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WIND-TUNNEL INVESTIGATION OF A PLAIN AND A SLOT-LIP AILERON ON A WING WITH A FULL-SPAN SLOTTED FLAP

By Francis M. Rogallo and Bartholomew S. Spano

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

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SUMMARY

An investigation was made in the NACA 7- by 10-foot wind tunnel of a slot-lip aileron and a plain aileron singly and in combination on an NACA 23012 wing with a 0.2566c full-span slotted flap. The static rolling, yawing, and hinge moments were determined and are presented for several angles of attack and flap deflections. The aileron-control characteristics were computed for slot-lip and plain ailerons linked together in several different ways. The results indicated that these devices may be combined so as to provide satisfactory aileron-control characteristics throughout the useful flight range on a wing with a full-span slotted flap. Flight tests are recommended.

INTRODUCTION

The NACA has recently undertaken an extensive investigation for the purpose of developing lateral-control devices primarily for use with full-span trailing-edge high-lift devices. A large variety of spoiler, deflector, and slot lateral-control devices were tested on model wings with full-span split and slotted flaps; static rolling, yawing, and hinge moments and time response were determined. (See reference 1.) The most satisfactory of these devices appeared to be a one-piece, plug-type, spoiler-slot aileron, the wind-tunnel development of which was reported in reference 2.

More recently an effort has been made to develop other promising lateral-control systems for use with full-span flaps, particularly systems comprising conventional devices and their combinations. An analysis of the results presented in reference 3 indicated that a combination of plain and slot-lip ailerons might provide satisfactory lateral control at all useful flight conditions. The slot-lip aileron of reference 3 utilized the trailing edge of the main portion of the airfoil, and the plain aileron was located at the trailing edge of the slotted flap. These ailerons were tested separately in a two-dimensional flow set-up; the positive-deflection range of the slot-lip aileron was not covered.

In the present investigation plain and slot-lip ailerons similar to those of reference 3 were tested in combination over the outer 37 percent of the semispan of a rectangular NACA 23012 wing with a full-span NACA slotted flap. These tests covered both positive and negative deflections of the ailerons. From the test results aileron-control characteristics were computed for plain and slot-lip ailerons linked together in several ways. The computed characteristics are included with the test results in the present report.

APPARATUS AND METHODS

All tests were made in the NACA 7- by 10-foot closed-throat wind tunnel (see reference 4) at an air speed of about 40 miles per hour, corresponding to a test Reynolds number of 1,500,000. The ailerons were installed in the outer 0.37b/2 of a 4- by 8-foot NACA 23012 wing with a 0.2566c full-span slotted flap, as shown in figures 1 and 2. The flap installation was that designated 2-h in reference 4, and the flap was operated along the paths shown in figure 2. The wing was suspended horizontally in the wind tunnel with the inboard end attached to the tunnel wall so as to simulate the semispan of a 4- by 16-foot rectangular wing. The attachment at the tunnel wall restrained the wing in pitch but not in roll or yaw. The forces necessary to restrain the outboard end of the wing were determined by means of the regular balance system. The lift of the wing with the ailerons neutral was computed from the vertical outboard reaction and the assumption that the lateral center of pressure of the semispan was 0.45b/2 from the plane of symmetry. The rolling moment was computed from the difference between the vertical reactions at the outboard end of the wing with ailerons neutral and deflected; the yawing moment was determined similarly from the horizontal reactions.

The ailerons were manually operated by means of cranks outside the tunnel wall near the inboard end of the model. The aileron hinge moments were determined by means of calibrated torque rods connecting the ailerons and the cranks.

RESULTS

In the presentation of results, the following symbols are used:

C_L lift coefficient $\left(\frac{L}{qS}\right)$

C_l' rolling-moment coefficient $\left(\frac{L'}{qbS}\right)$

C_n' yawing-moment coefficient $\left(\frac{N'}{qbS}\right)$

C_{h_a} hinge-moment coefficient $\left(\frac{H_a}{qS_a c_a}\right)$

H_a aileron hinge moment

c wing chord

c_a aileron chord measured along the airfoil chord line from the hinge axis of the aileron to the trailing edge of the aileron

L twice the lift on the half-span model

S twice the area of the half-span model

S_a aileron area behind hinge line

b twice the span of the half-span model

L' rolling moment about wind axis

N' yawing moment about wind axis

q dynamic pressure of air stream

α uncorrected angle of attack

δ aileron or flap deflection, positive when trailing edge moves down

Subscripts:

a aileron

sl slot-lip aileron

p plain aileron

f flap

A positive value of L' or C_l' corresponds to a decrease in lift on the model, and a positive value of N' or C_n' corresponds to an increase in drag on the model. Twice the actual lift, area, and span of the model were used in the reduction of results because the model represents half of a complete wing, as has been previously stated. No corrections have been made for the effect of the tunnel walls. Such corrections might, however, be relatively large for the test installation used.

The results for the flap-neutral condition (see fig. 3) were obtained with the bottom of the flap slot covered and sealed, except for one test at $\alpha = 8^\circ$. (See fig. 3 (b).) Comparison of the results of this test with those of the corresponding test for the slot-sealed condition shows that sealing the slot decreases the rolling-moment effectiveness of the slot-lip aileron, particularly at low aileron deflections, and considerably alters its hinge-moment characteristics, as was to be expected from the results of references 1, 2, and 5. Slot-lip aileron results obtained with the slot open, as given in reference 3, are therefore not directly applicable to designs incorporating a covered slot.

Aerodynamic characteristics of the two ailerons with the flap in its optimum high-lift positions at deflections of 20° and 30° are given in figures 4 and 5, respectively. Characteristics of the slot-lip aileron alone with the flap in its optimum positions at deflections of 40° and 50° are given in figure 6, where it may be seen that very little positive deflection of the aileron would be permissible because of the adverse effect on rolling moment and because the aileron contacts the flap. In order to allow a greater positive movement of the slot-lip aileron and to improve the rolling moment, the flap was lowered to the positions indicated by the modified path in figure 2, and combination tests of the two ailerons were made. (See figs. 7 and 8.) The effect of the change of flap location on $C_{L_{max}}$, as estimated from the data of reference 4, is less than 3 percent.

The results presented herein may be compared with those of semispan plain and slot-lip ailerons as computed from section data. (See reference 3.) The ailerons of the present investigation (0.37b/2) should develop about half as much rolling-moment coefficient as those of reference 3 if the method of computation employed in reference 3 were directly applicable. (See fig. 13 of reference 6.) In some conditions, however, particularly for the slot-lip aileron at large angles of attack and flap deflections, the 0.37b/2 aileron produced as much rolling-moment coefficient as was computed for the semispan device. The large discrepancies noted indicate that for devices of this type the effects of cross flow are of great importance, and the effect of changes in the size and location of spoiler-type or slot-lip ailerons cannot be computed by the same methods as employed for plain ailerons on plain wings. This conclusion is in agreement with reference 6 which states that, "The charts cannot be used with devices that change the slope of the lift curve nor for excessive deflections that introduce disturbed air flow." The slot-lip aileron probably does both.

DISCUSSION OF CALCULATED RESULTS

In order to illustrate the use of the test data herein presented, aileron-control characteristics were computed for the ailerons and the wing arrangement of a pursuit airplane as shown in figure 9. The span of the slot-lip aileron shown is 0.37b/2, the same as that on the wind-tunnel model, and the span of the plain aileron is 0.56b/2, approximately 50 percent greater than that on the wind-tunnel model. The chords of both ailerons are 10 percent of the mean chord of that portion of the wing in which the ailerons are located. The lift coefficient of the representative airplane at any particular angle of attack and flap deflection was assumed to be that of the wing in the tunnel, computed as described under Apparatus and Methods. These lift coefficients may not, however, be realized on the airplane.

Plain ailerons.- The characteristics of the plain ailerons of figure 9 linked for equal up and down deflections to a maximum of ±15° have been computed for slotted-flap deflections of 0° and 20°. (See fig. 10.) A differential linkage that gives approximately the same maximum rolling moment as the equal up and down deflections of ±15° is shown in figure 11. With this linkage a stick deflection δ_1 of 21° gives aileron deflections of 10.7° and -19.7°. The computed aileron-control characteristics of this system (see fig. 12) are not significantly different from those of the equal-deflection system. Although the equal-deflection system has slightly lower stick forces at maximum deflection in the high-speed condition, it has generally greater adverse yawing moments. The characteristics given in figures 10 and 12 were computed from the data of figures 3 and 4 and the simple but approximately correct assumption (see fig. 13, reference 6) that hinge, rolling, and yawing moments are proportional to the span of the plain ailerons. The characteristics of the plain ailerons alone were not computed for the flap at deflections of 30° or above because of the large adverse yawing moments to be expected. If that portion of the flap covered by the ailerons were limited to a deflection of about 20°, however, a lateral-control system employing plain ailerons alone might be considered satisfactory.

Slot-lip ailerons.- Because of the limited down deflection of the slot-lip aileron, control systems employing it require an extreme differential linkage such as that shown in figure 11 over the range corresponding to a differential crank deflection θ_d of 50°. This differential linkage and the large up-floating tendency of the ailerons cause an overbalancing of the system, particularly in the high-lift condition, as shown in figure 13. This unsatisfactory stick-force may be remedied, however, by the installation of springs in the system, as shown schematically in figure 13. The spring arrangement shown gave the best resultant stick-force characteristics of the several considered.

Lateral-control characteristics of the slot-lip ailerons with the spring arrangement shown in figure 13 have been computed for slotted-flap deflections from 20° to 50°. (See fig. 14.) Each aileron was assumed to have the characteristics shown in figures 4, 5, 7, and 8, without corrections for tunnel effect or plan form variations. With the flap at 20° the stick forces may be excessive. In view of the high rolling moments produced by this system relative to those of conventional ailerons, however, it appears practicable to reduce the stick forces through a reduction of the span, chord, or deflection of the ailerons. Such a modification would also tend to eliminate the extremely rapid rise of rolling moment with initial stick deflection at flap deflections of 40° and 50°. In general, the characteristics of this system improve with flap deflection, whereas the opposite is true for the plain aileron.

No computations were made for slot-lip ailerons alone with the flap completely retracted because the linkage assumed (see fig. 11) would not permit movement of the ailerons. Although the linkage could be modified to permit deflection of the upgoing aileron only, no lateral-control system employing such a linkage has ever been generally accepted. If the slot-lip ailerons were uprigged about 10° when the flap was retracted, a differential system similar to that of figure 11 could be employed. The uprigging would also tend to eliminate the effect of the initial flat spot in the rolling-moment curves. (See fig. 3.) Before such an arrangement is given serious consideration, however, the drag increase accompanying the aileron uprigging should be determined.

<u>Slot-lip and plain aileron combinations</u>.- A control system could be designed to permit the use of plain ailerons alone up to flap deflections of about 20° and slot-lip ailerons alone at all greater flap deflections, the shift from one device to the other being made abruptly. If a gradual transition is desired it may be made by means of a system such as is shown schematically in figure 15. The aileron-control characteristics at a flap deflection of 20° with the linkage system of figure 15 in an intermediate position (linkage A_2, table I) are shown in figure 16. The plain ailerons are deflected equally up and down to ±8.3° and the slot-lip ailerons are deflected a maximum of 19.7° up and 10.7° down. In the computation of these characteristics, and of those to

follow, it was assumed that the hinge-moment coefficients of each of the two types of aileron, when in combination, were as given in figures 3 to 8, even though in the assumed arrangement (see fig. 9) the plain aileron extends beyond the slot-lip aileron at both the inboard and the outboard ends. It is known that there is some spanwise spread of the disturbed flow region behind the slot-lip ailerons, but this spread may not be sufficient to cover the plain aileron of figure 9. In the computation of the rolling- and the yawing-moment coefficients the increments of C_l' and C_n' due to deflection of the plain aileron, when in combination with the slot-lip aileron, were increased by 50 percent of the increments shown in figures 3 to 8 in order to take account of the 50-percent increase in plain-aileron span. It should be remembered that hinge-moment coefficients are based on the chord and the area of the aileron, whereas rolling- and yawing-moment coefficients are based on the span and the area of the complete wing. Increasing the span of a device may therefore increase the actual hinge moment proportionately with the increase in aileron span even though the hinge-moment coefficient may remain unchanged.

With the linkage system shown in figure 15 adjusted to give simultaneous deflections of the adjacent slot-lip and plain ailerons of -46.6° and -25°, respectively, when the stick is deflected 21° (linkage A_3, table I) no springs are required to give acceptable stick-force variations with the flap deflected 30°. Computed characteristics of such a system at angles of attack of -6° and 15° are shown in figure 17; at intermediate angles of attack the curves would probably lie between those drawn. It will be seen that the adverse yawing-moment coefficients are very high at the high angle of attack, about one-third of the rolling-moment coefficients. The ratio of adverse yawing to rolling moment would be much higher at flap deflections of 40° and 50° than at 30°.

It appears that a reversal of the motion of the plain aileron relative to that of the slot-lip aileron might improve the lateral control at high flap deflections. With this possibility in mind a linkage system was designed (see fig. 18) to give the same differential ratio to the plain ailerons as to the slot-lip ailerons, but with the two moving in opposite directions at high flap deflections (linkage B_2, table I). The deflections of the plain ailerons in this combination were assumed to be one-third those of the adjacent slot-lip ailerons, but of the opposite sign. The rolling-moment characteristics at flap deflections of 30°, 40°, and 50° (see fig. 19) are not far different from those of the slot-lip ailerons alone. (See fig. 14.) The combination system has lower adverse yawing moments but higher stick forces and poorer stick-force variation. Control-linkage system A with springs, moreover, is considered less complicated and more reliable than linkage system B, even though system B requires no springs.

In the foregoing discussion only a few of the many possible methods of combining plain and slot-lip ailerons have been considered. The computed characteristics of the assumed systems appear to be satisfactory and could, no doubt, be further improved by a more complete study of aileron arrangements and linkages. It is not considered profitable, however, to spend very much time refining a proposed system on the basis of the wind-tunnel results presented in this report because the change of aerodynamic characteristics due to changes of plan form, wing section, and the arrangement and detail design of the ailerons may be large. The data presented are considered useful primarily for making a preliminary design of a particular installation that is to undergo further development either in a wind tunnel or in flight.

CONCLUDING REMARKS

On the basis of results presented herein it appears that slot-lip and plain ailerons may be combined so as to provide satisfactory aileron-control characteristics throughout the useful flight range on a wing with a full-span slotted flap. Flight tests are recommended.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

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2. Rogallo, Francis M., and Swanson, Robert S.: Wind-Tunnel Development of a Spoiler-Slot Aileron for a Wing with a Full-Span Slotted Flap. NACA ARR, Nov. 1941.

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TABLE I.- AILERON DEFLECTIONS CORRESPONDING TO A STICK DEFLECTION OF 21° TO THE RIGHT

Linkage (a)	Springs (b)	Right wing		Left wing		Figure (c)
		δ_p (deg)	δ_{sl} (deg)	δ_p (deg)	δ_{sl} (deg)	
A_1	No	-15	0	15	0	10
A_2	Yes	-8.3	-19.7	8.3	10.7	16
A_3	No	-25	-46.6	25	6.2	17
A_4	Yes	0	-46.6	0	6.2	14
B_1	No	-19.7	0	10.7	0	12
B_2	No	13.5	-46.6	-2.1	6.2	19

[a]Linkage A_1 to A_4 are obtained with linkage system A (see fig. 15). Linkage B_1 and B_2 are obtained with linkage system B (see fig. 18).

[b]Springs employed are as shown in figures 13 and 15.

[c]Figures showing computed aileron-control characteristics.

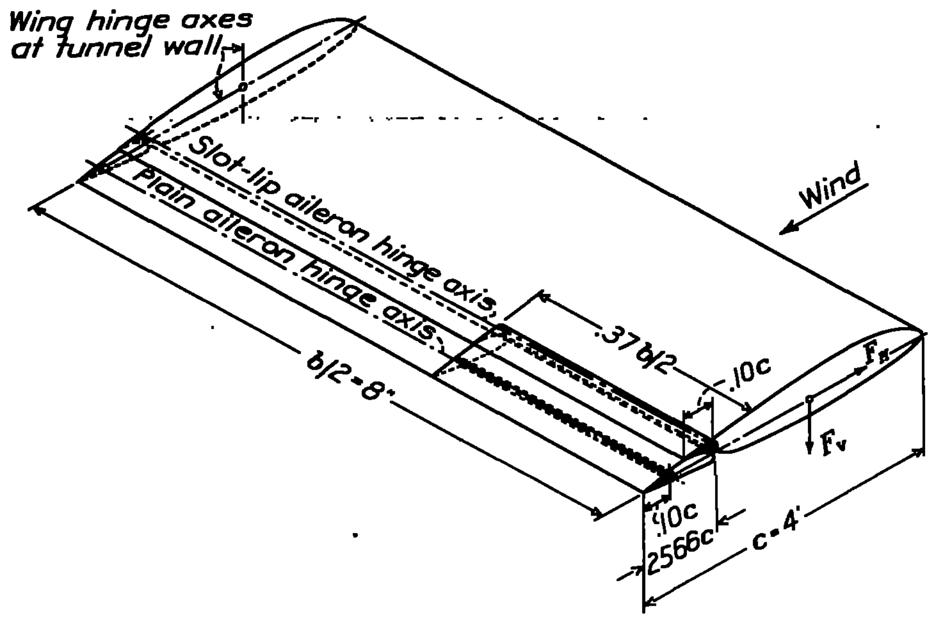


Figure 1.- Schematic diagram of test set-up.

Flap nose path from reference 4.

δ_f ,(deg)	x ,%c	y ,%c
0	8.36	3.91
20	3.83	3.45
30	2.63	3.37
40	1.35	2.43
50	.50	1.63

Modified path.

δ_f ,(deg)	x ,%c	y ,%c
40	1.50	3.20
50	.50	2.50

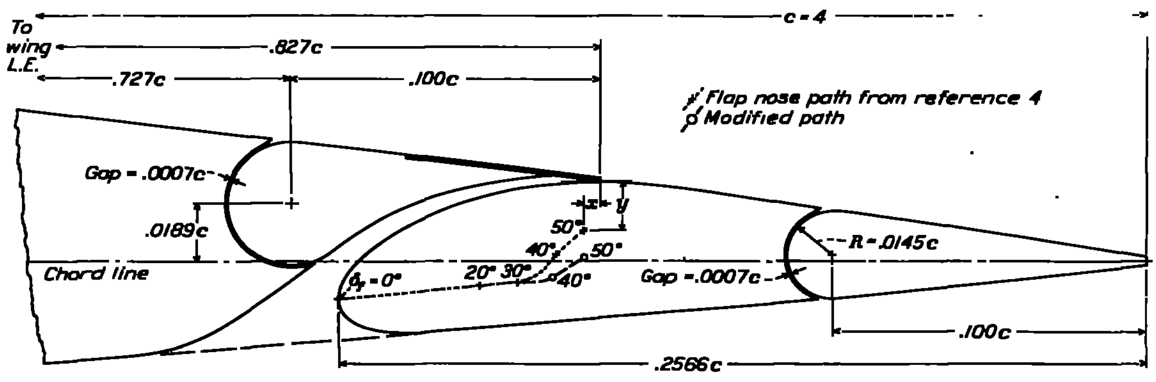


Figure 2.- The 0.37 b/2 slot-lip and plain ailerons on an 8-foot semispan NACA 23012 wing with a 0.2566c full-span slotted flap.

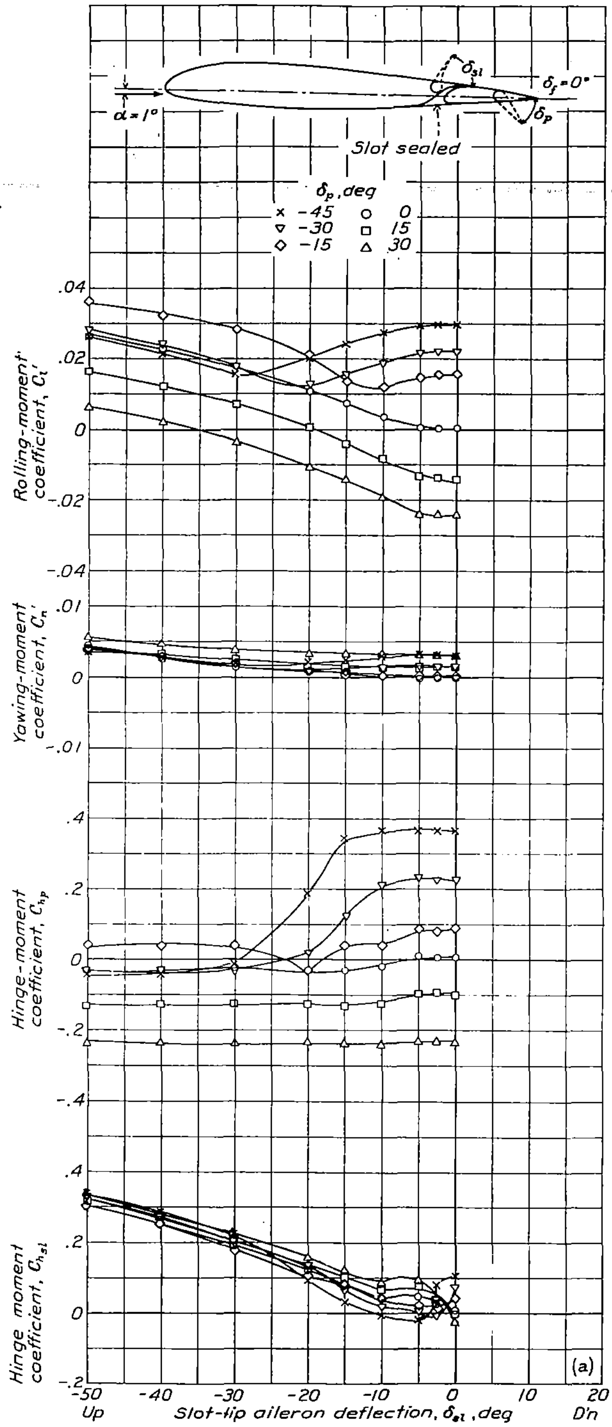


Figure 3a.- α , 1°; C_L , 0.17

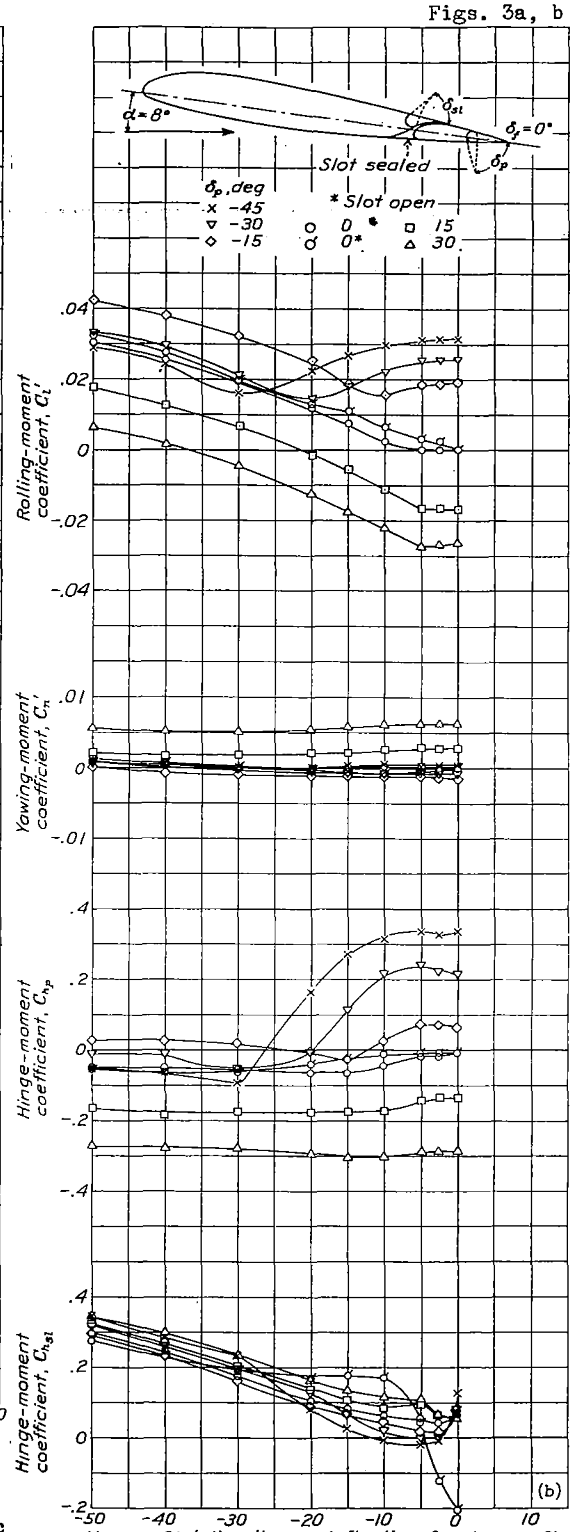


Figure 3b.- α , 8°; C_L , 0.76

Figure 3a to c.- Aerodynamic characteristics of 0.10c by 0.37 b/2 plain and slot-lip ailerons on an 8-foot semispan NACA 23012 wing with a 0.2566c full-span slotted flap. Flap retracted; slot closed.

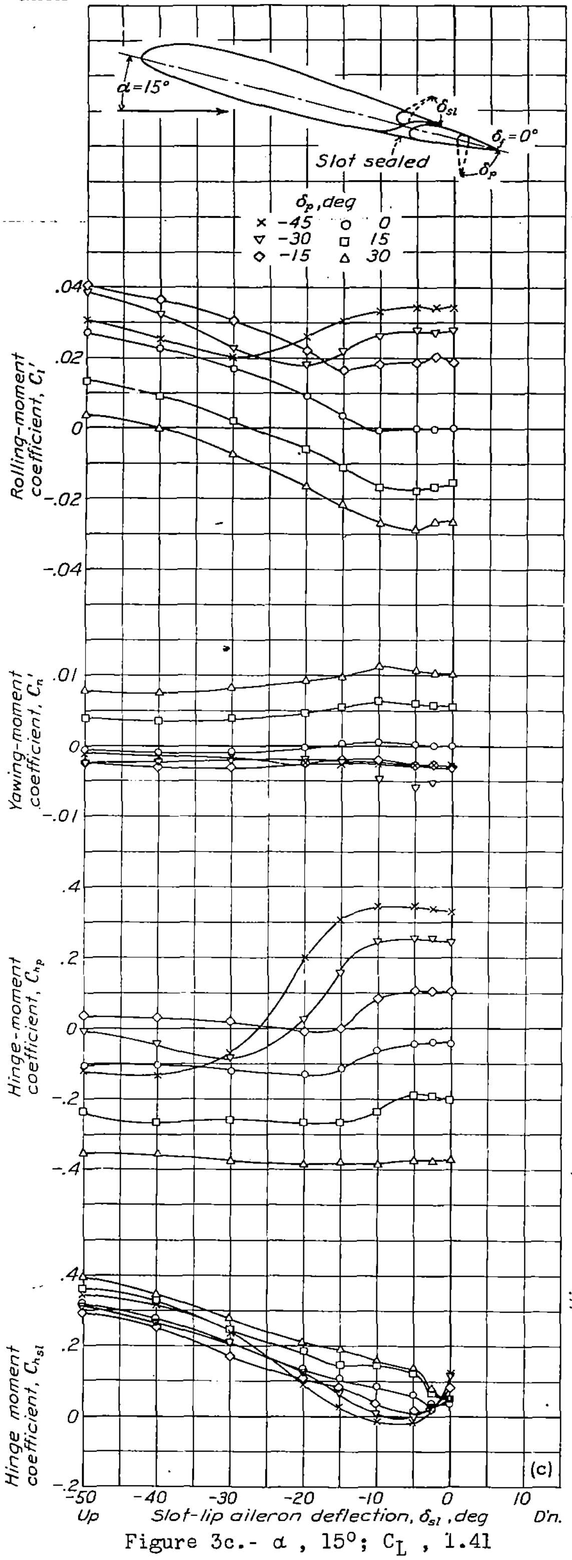


Figure 3c.- α , 15°; C_L , 1.41

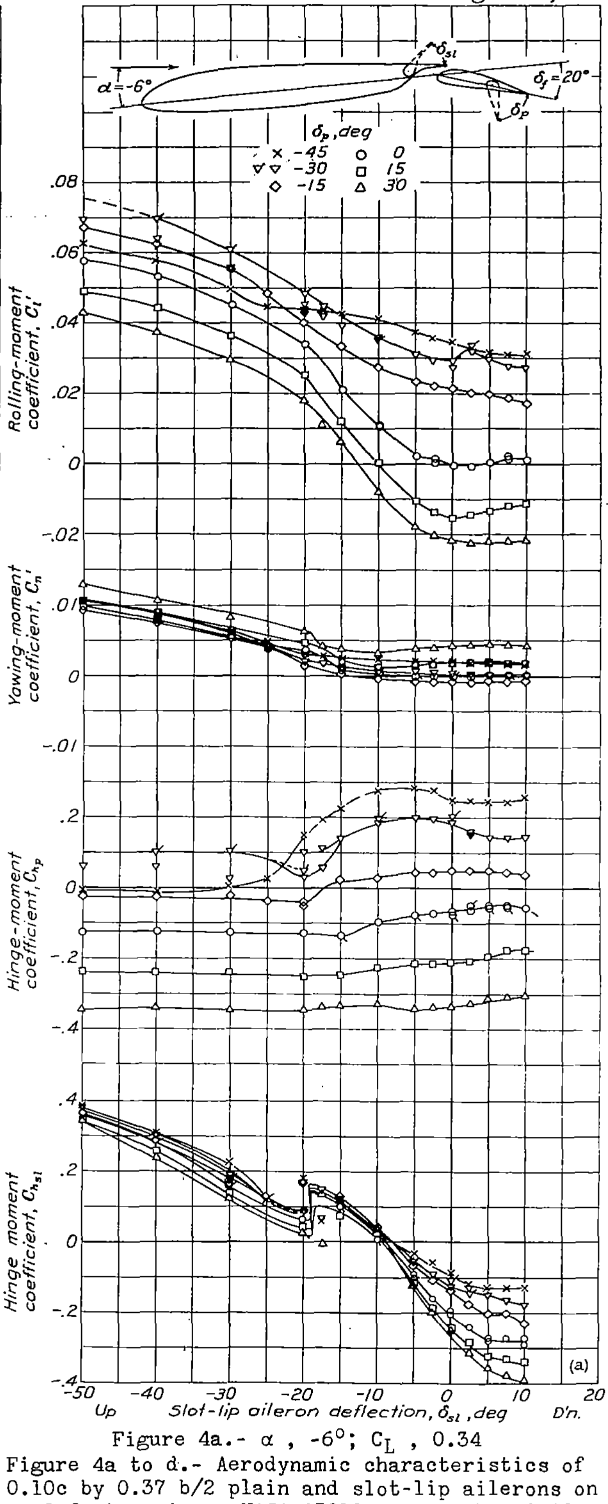


Figure 4a.- α , -6°; C_L , 0.34

Figure 4a to d.- Aerodynamic characteristics of 0.10c by 0.37 b/2 plain and slot-lip ailerons on an 8-foot semispan NACA 23012 wing with a 0.2566c full-span slotted flap; δ_f = 20°.

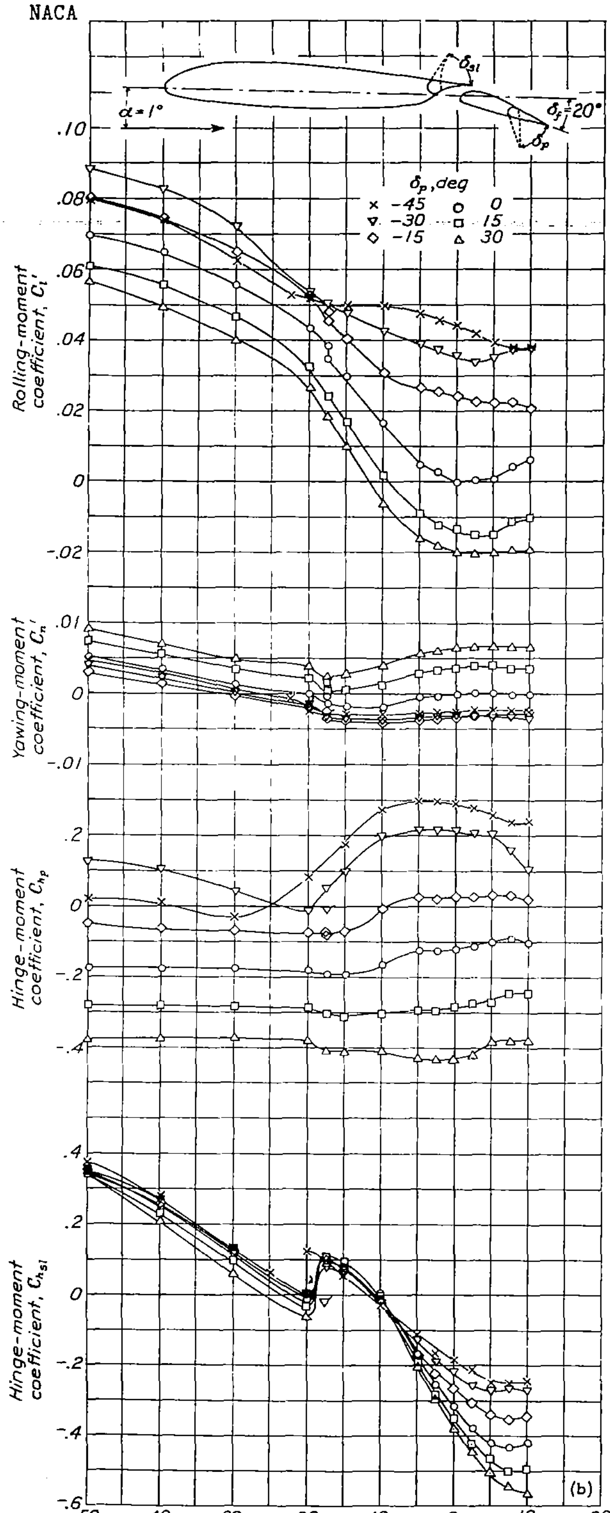


Figure 4b.- α, 1°; C_L, 1.04

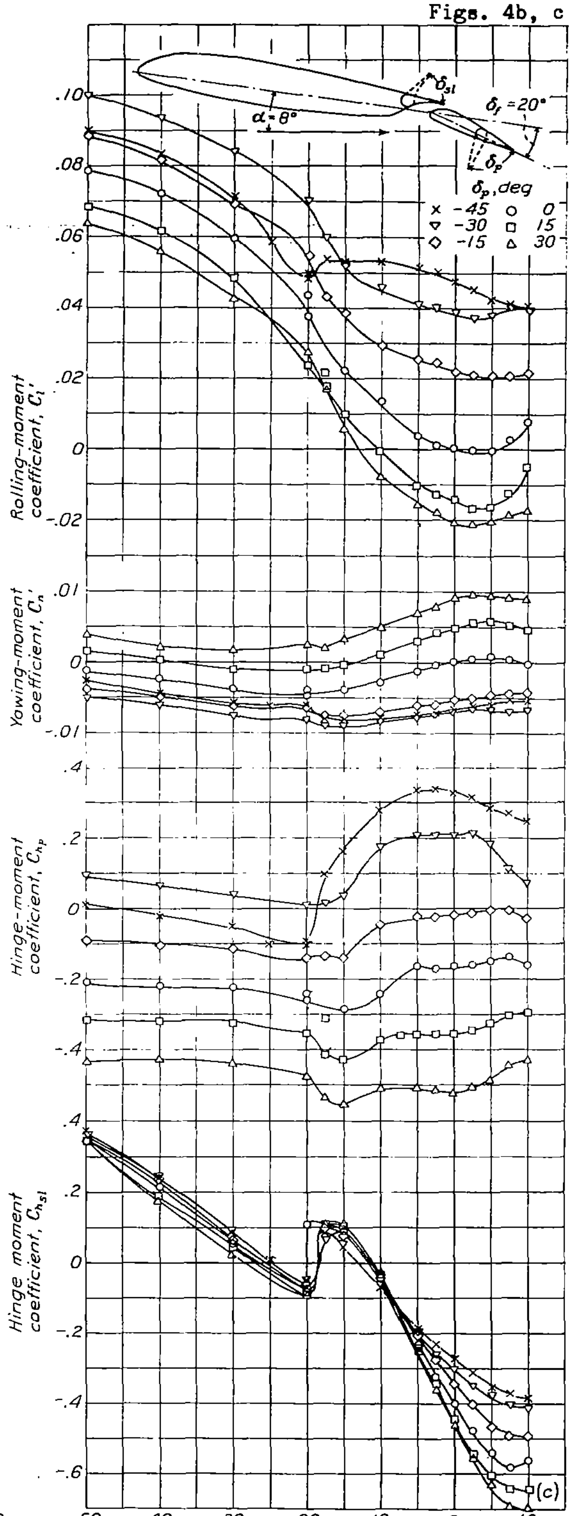


Figure 4c.- α, 8°; C_L, 1.71

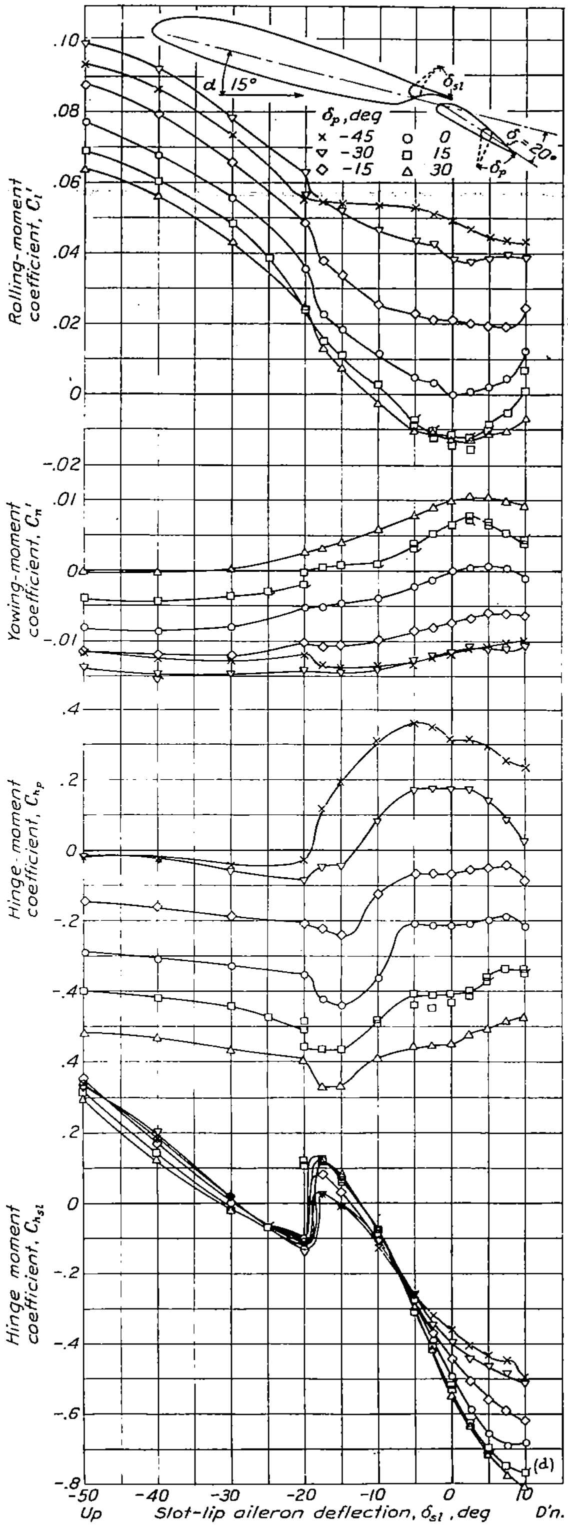


Figure 4d.- α , 15°; C_L , 2.34

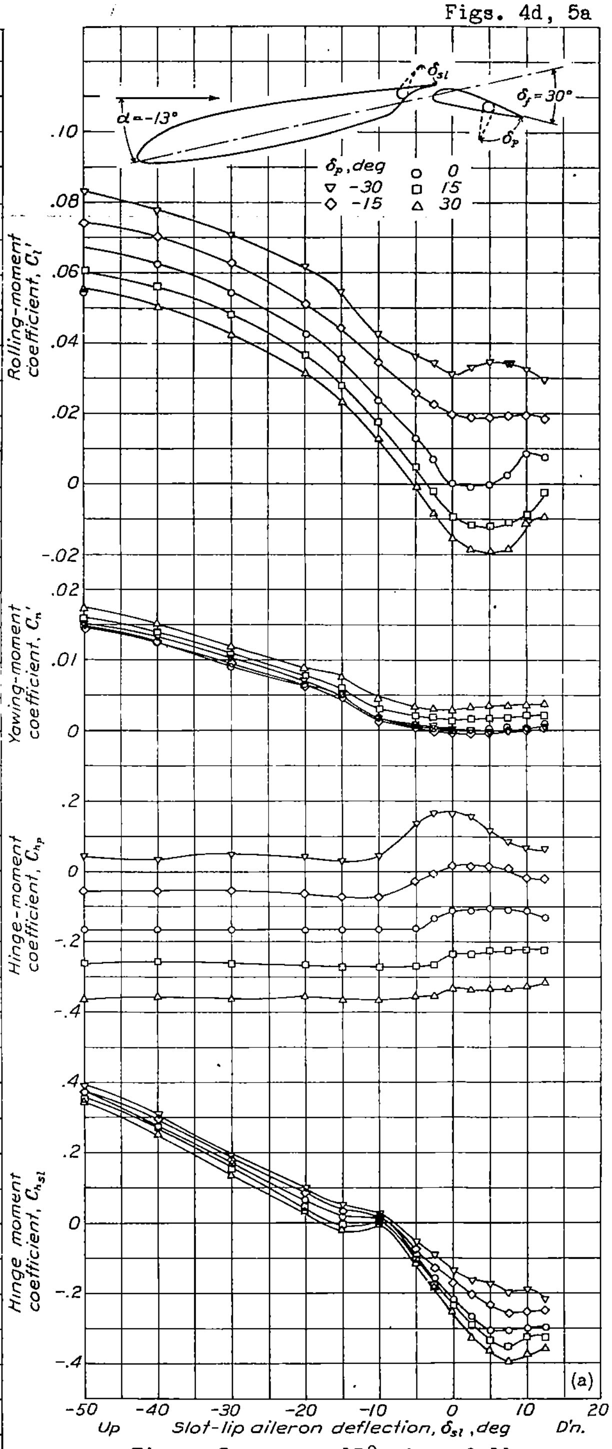


Figure 5a.- α , -13°; C_L , 0.11

Figure 5a to e.- Aerodynamic characteristics of 0.10c by 0.37 b/2 plain and slot-lip ailerons on an 8-foot semispan NACA 23012 wing with a 0.2566c full-span slotted flap; δ_f = 30°.

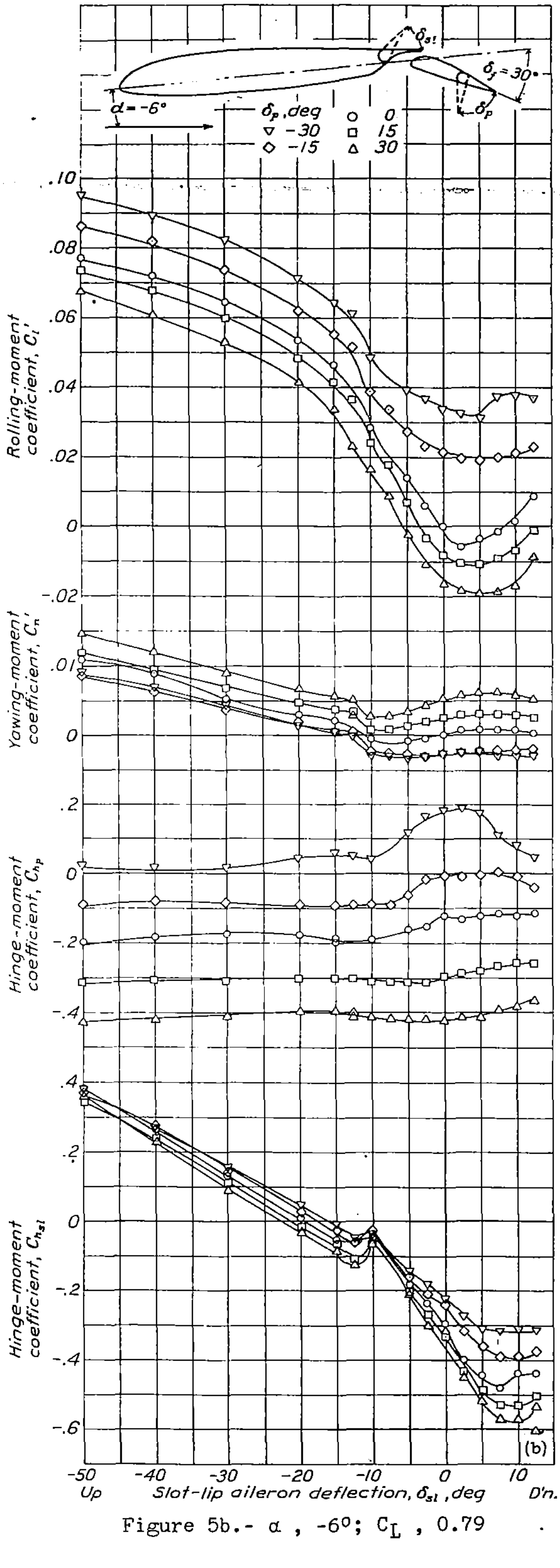


Figure 5b.- α, -6°; C_L, 0.79

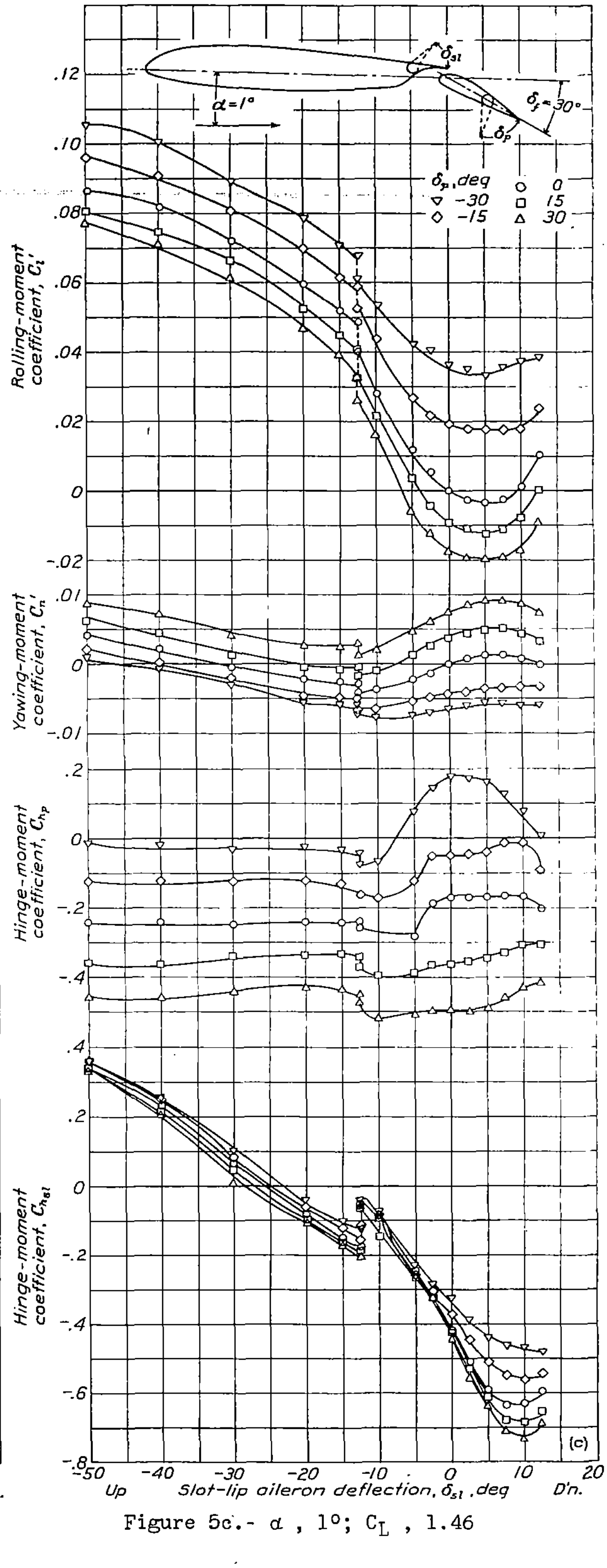


Figure 5c.- α, 1°; C_L, 1.46

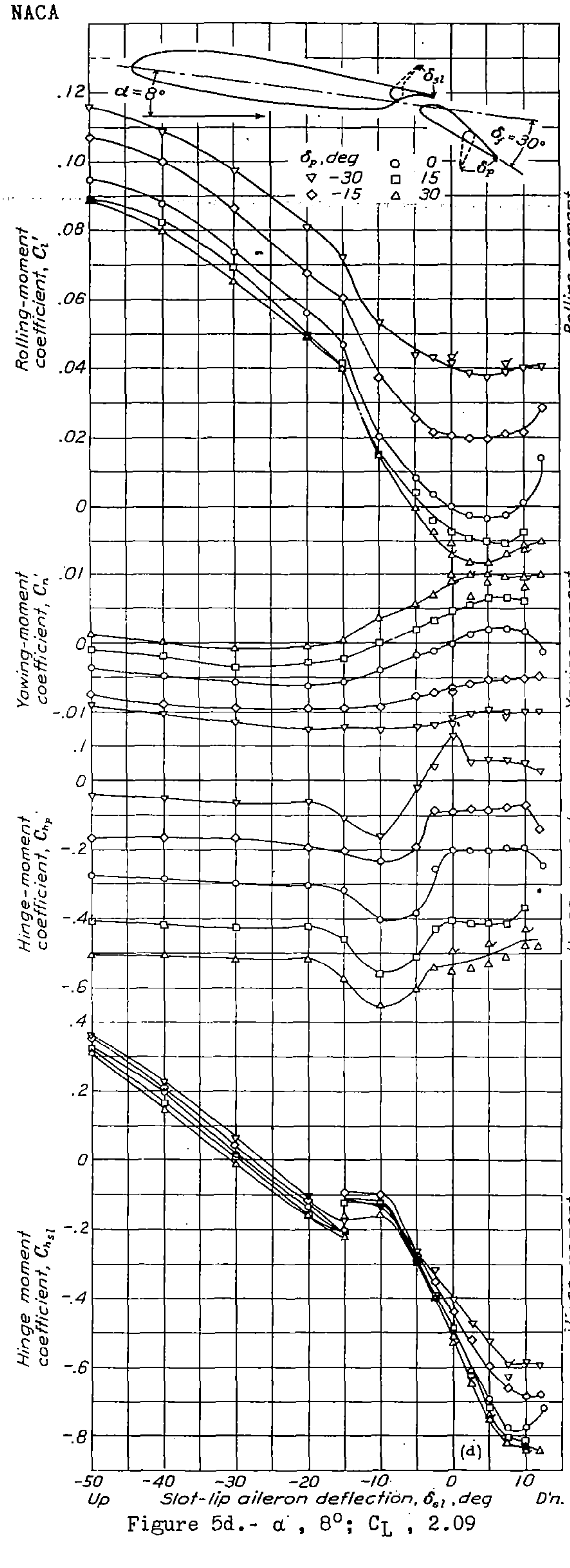


Figure 5d.- α , 8°; C_L , 2.09

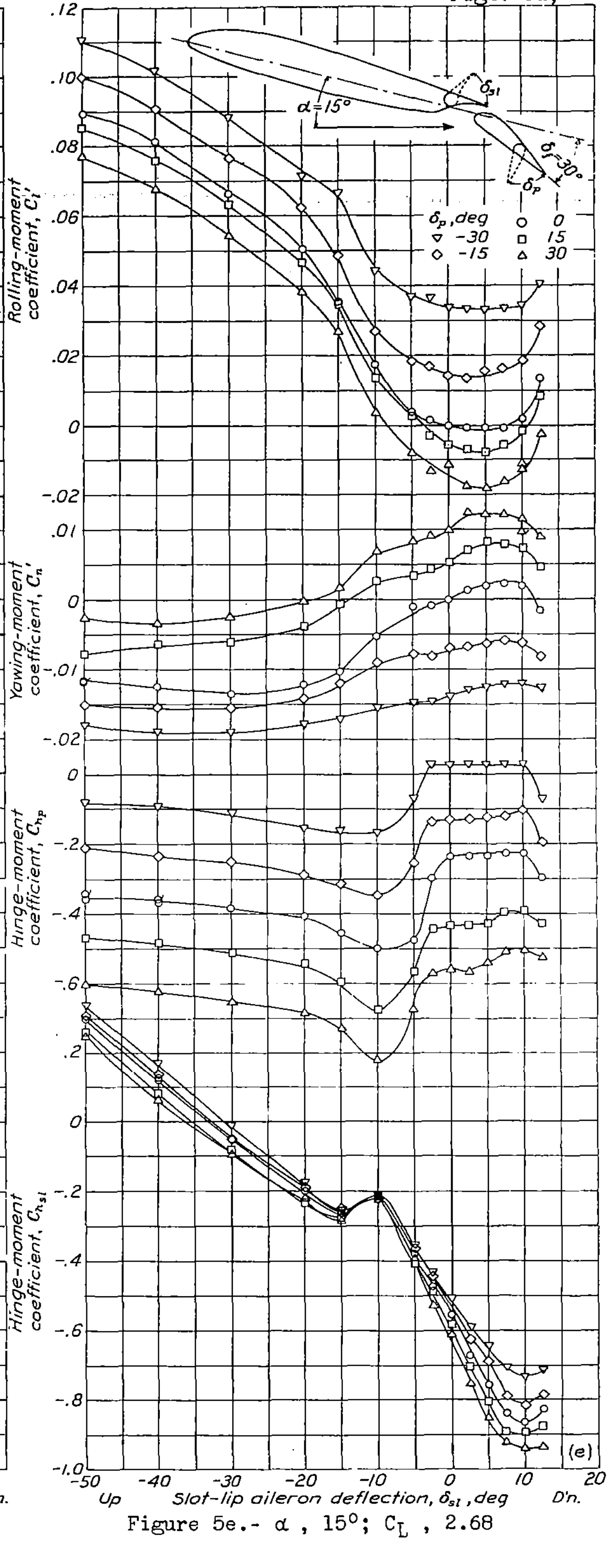


Figure 5e.- α , 15°; C_L , 2.68

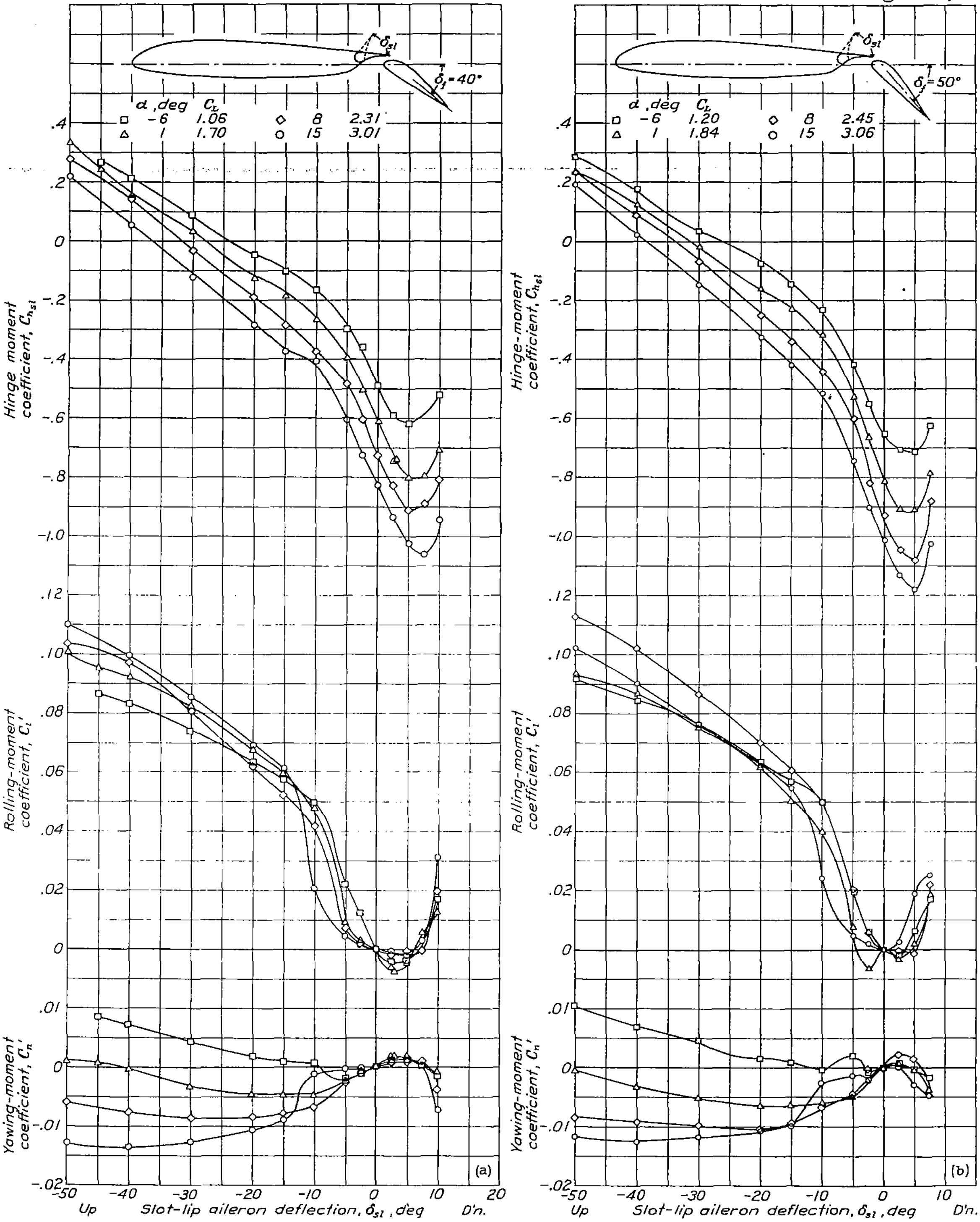


Figure 6a.- δ_f = 40°

Figure 6b.- δ_f = 50°

Figure 6a to b.- Aerodynamic characteristics of a 0.10c by 0.37 b/2 slot-lip aileron on an 8-foot semispan NACA 23012 wing with a 0.2566c full-span slotted flap. Flap nose location at optimum positions recommended in reference 4.

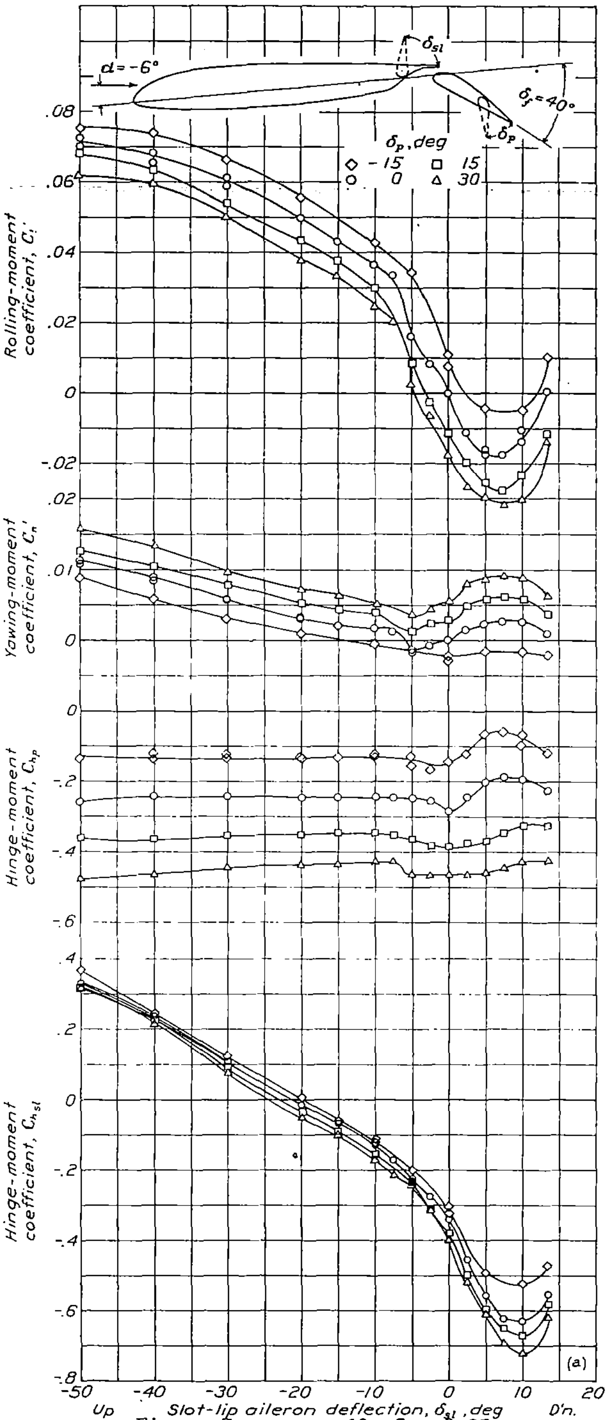


Figure 7a.- α, -6°; C_L, 0.83

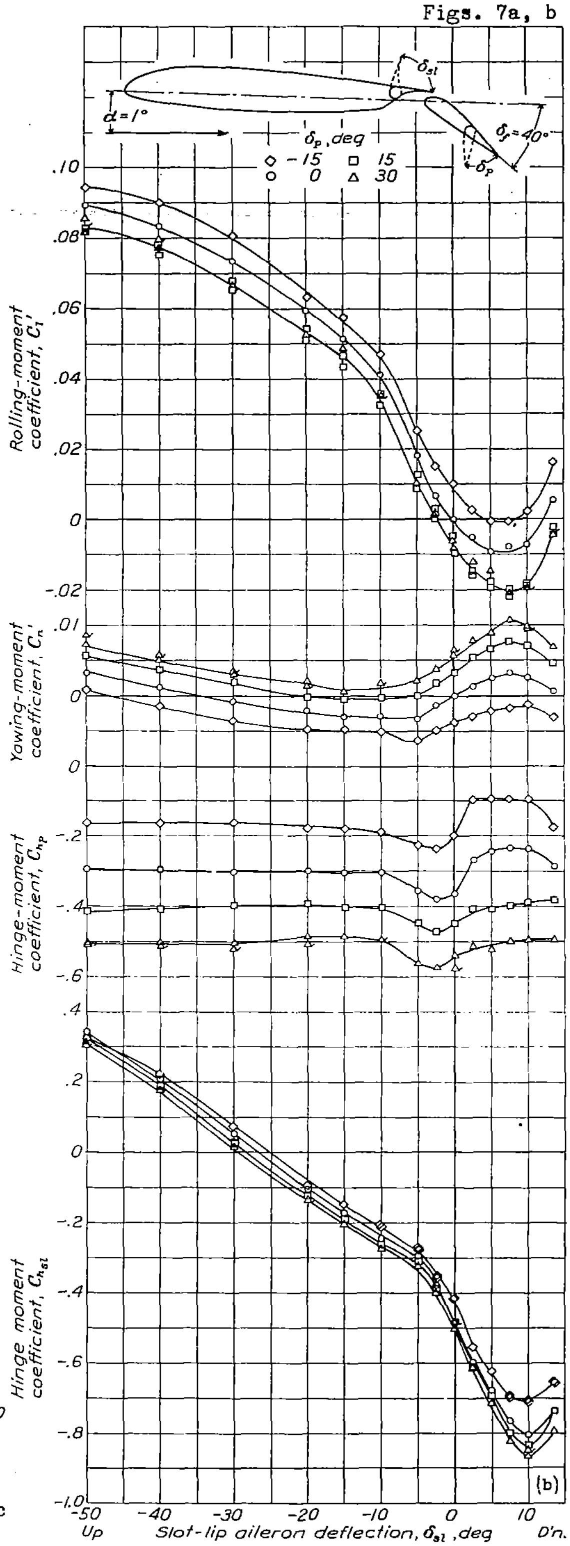


Figure 7b.- α, 1°; C_L, 1.54

Figure 7a to d.- Aerodynamic characteristics of 0.10c by 0.37 b/2 plain and slot-lip ailerons on an 8-foot semispan NACA 23012 wing with a 0.2566c full-span flap; $\delta_f = 40°$; flap nose location; x = 0.0150c, y = 0.0320c.

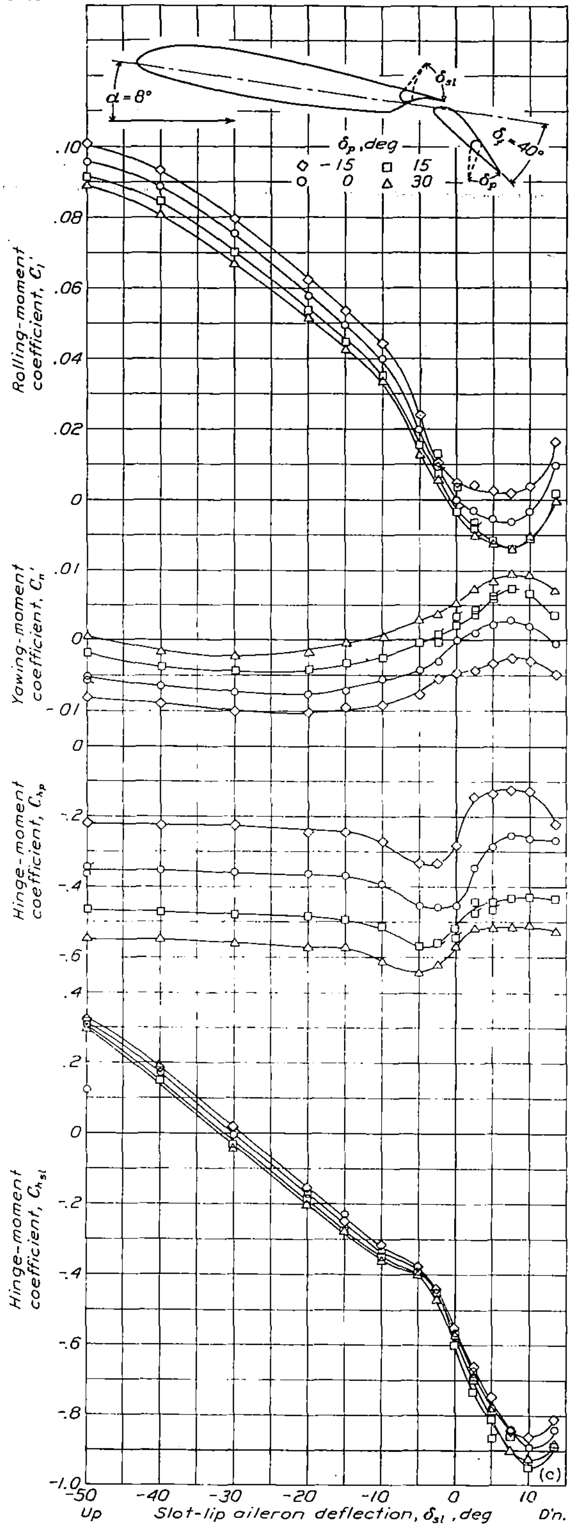


Figure 7c.- α, 8°; C_L, 2.19

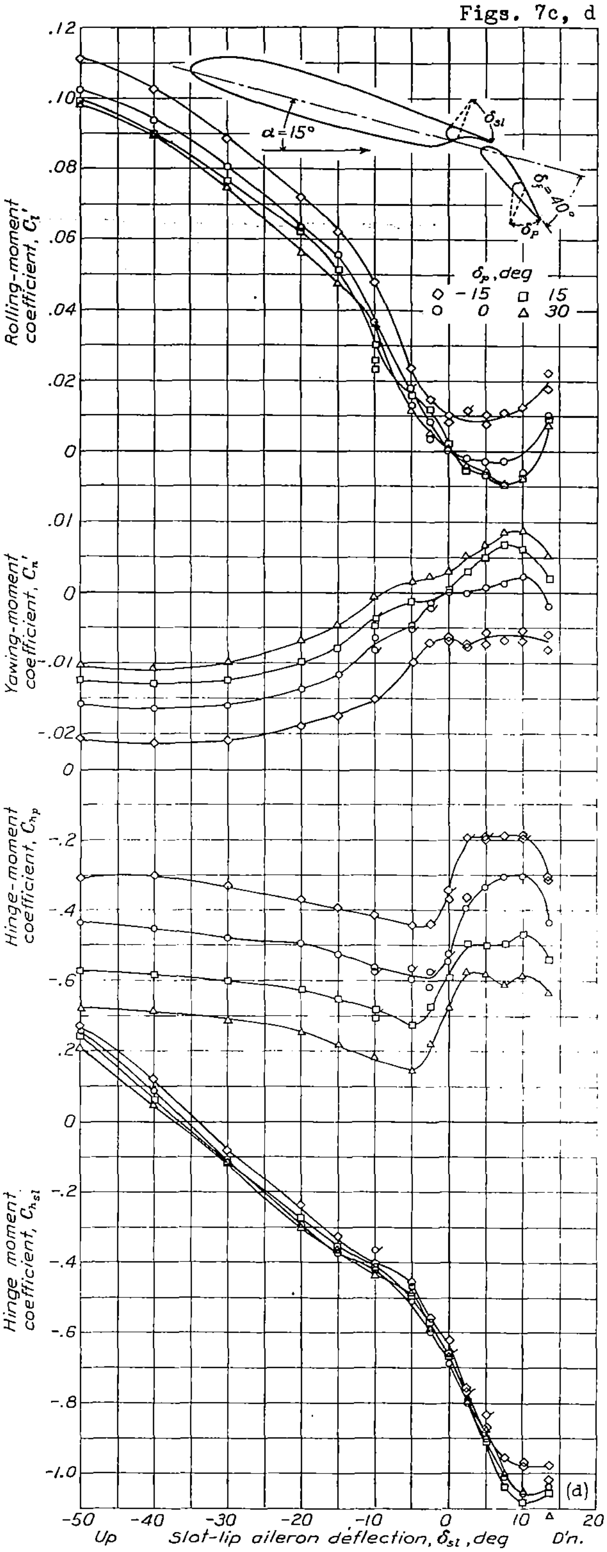


Figure 7d.- α, 15°; C_L, 2.95

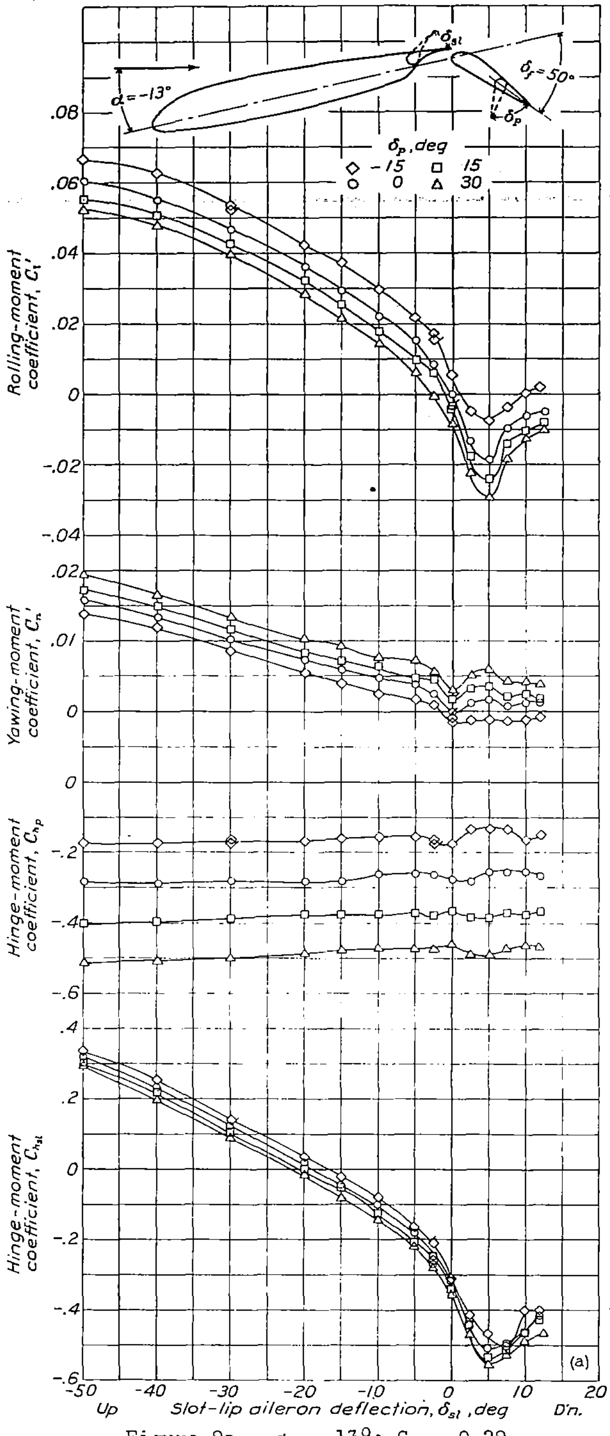


Figure 8a.- α, -13°; C_L, 0.28

Figure 8a to e.- Aerodynamic characteristics of 0.10c by 0.37 b/2 plain and slot-lip ailerons on an 8-foot semispan NACA 23012 wing with a 0.2566c full-span slotted flap; δ_f=50°; flap nose location: x = 0.0050c, y = 0.0250c.

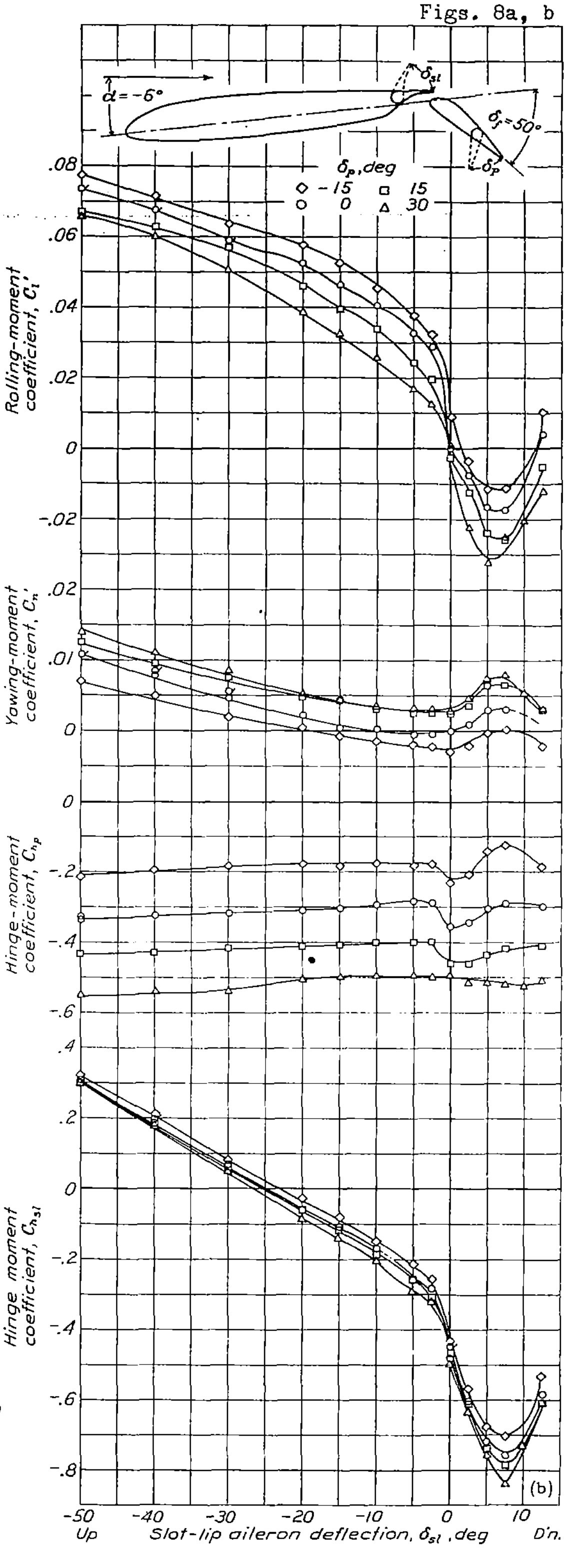


Figure 8b.- α, -6°; C_L, 0.92

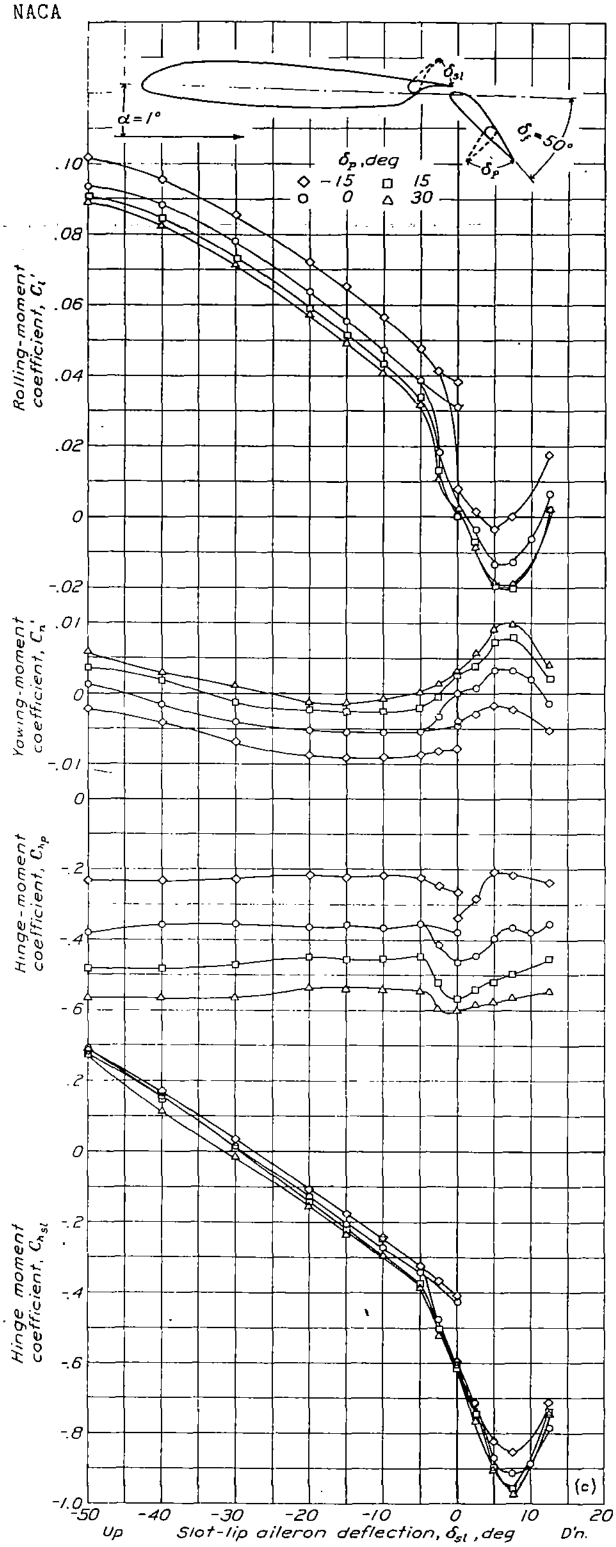


Figure 8c.- α , 1°; C_L , 1.65

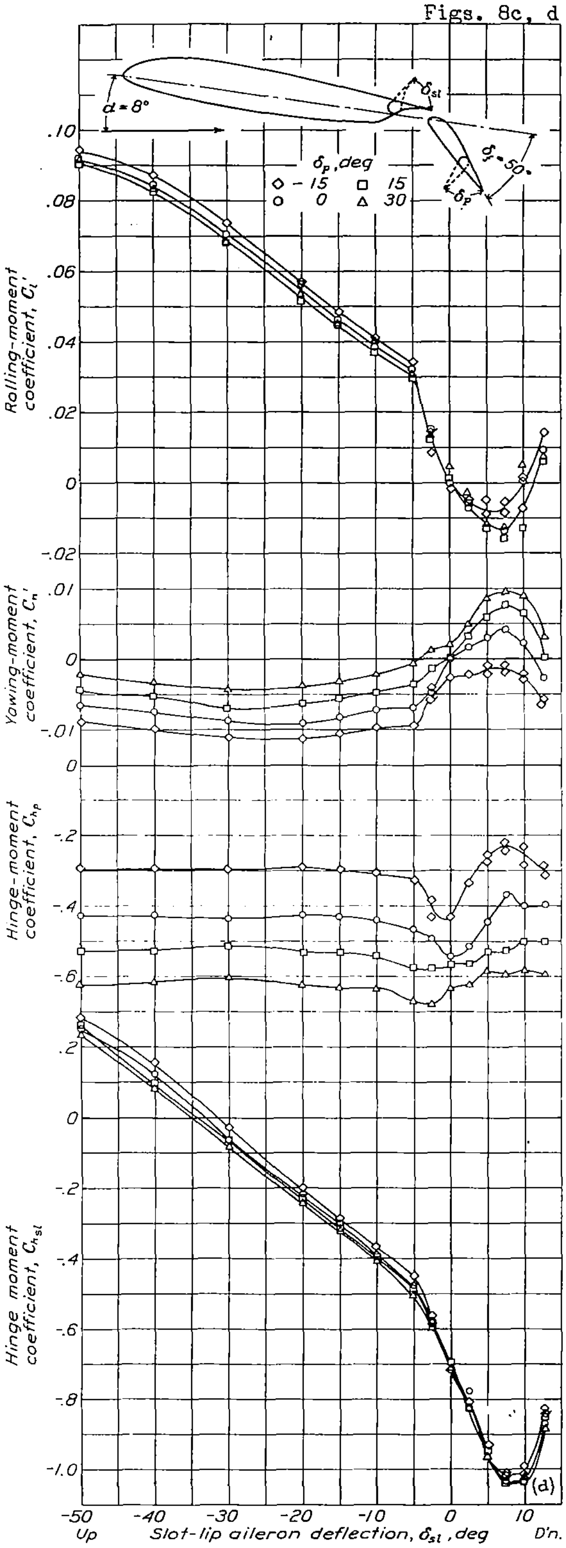


Figure 8d.- α , 8°; C_L , 2.23

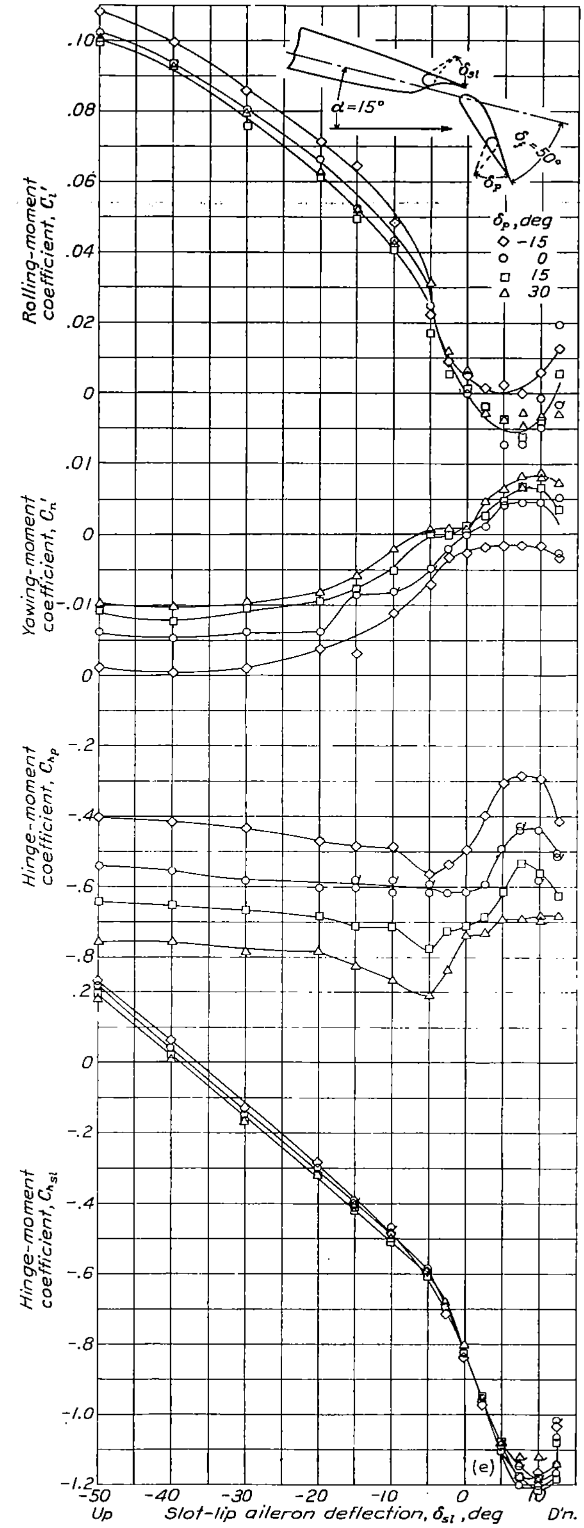
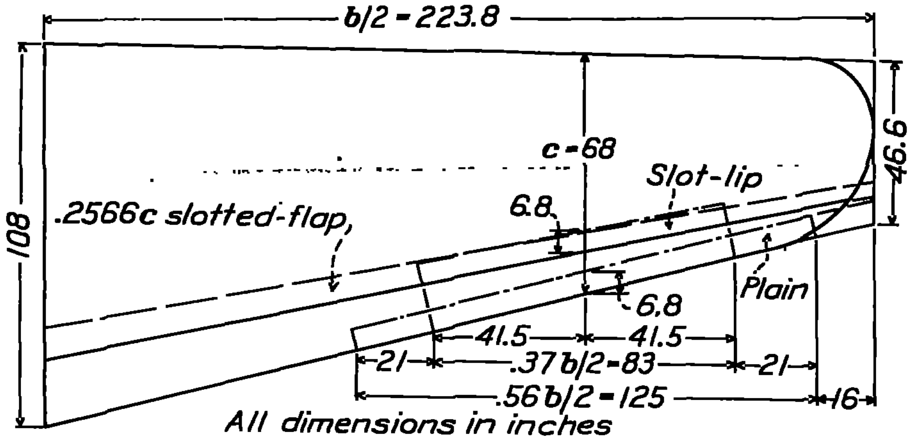


Figure 8e.- α , 15°; C_L , 3.01



Gross weight 6783 pounds
Wing area 236 square feet
Stick length 2 feet
Stick deflection ±21°

Figure 9.- Assumed aileron and slotted-flap arrangement on a pursuit airplane wing.

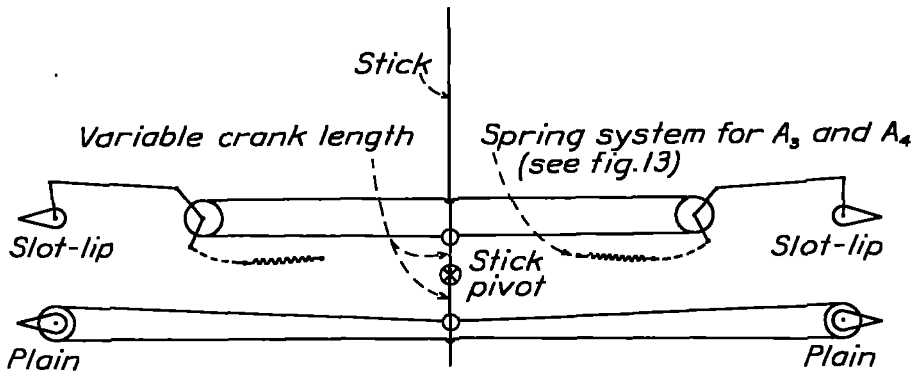
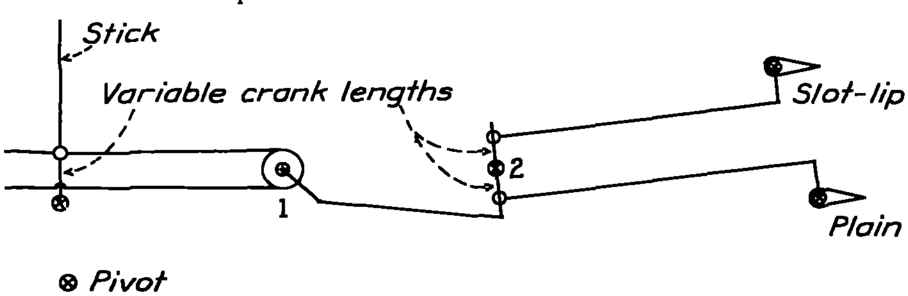


Figure 15.- Schematic diagram of linkage system A to operate ailerons in combination.



All differential motion is assumed to take place between pivots 1 and 2 as shown in figure 11.

Figure 18.- Schematic diagram of linkage system B to operate ailerons in combination.

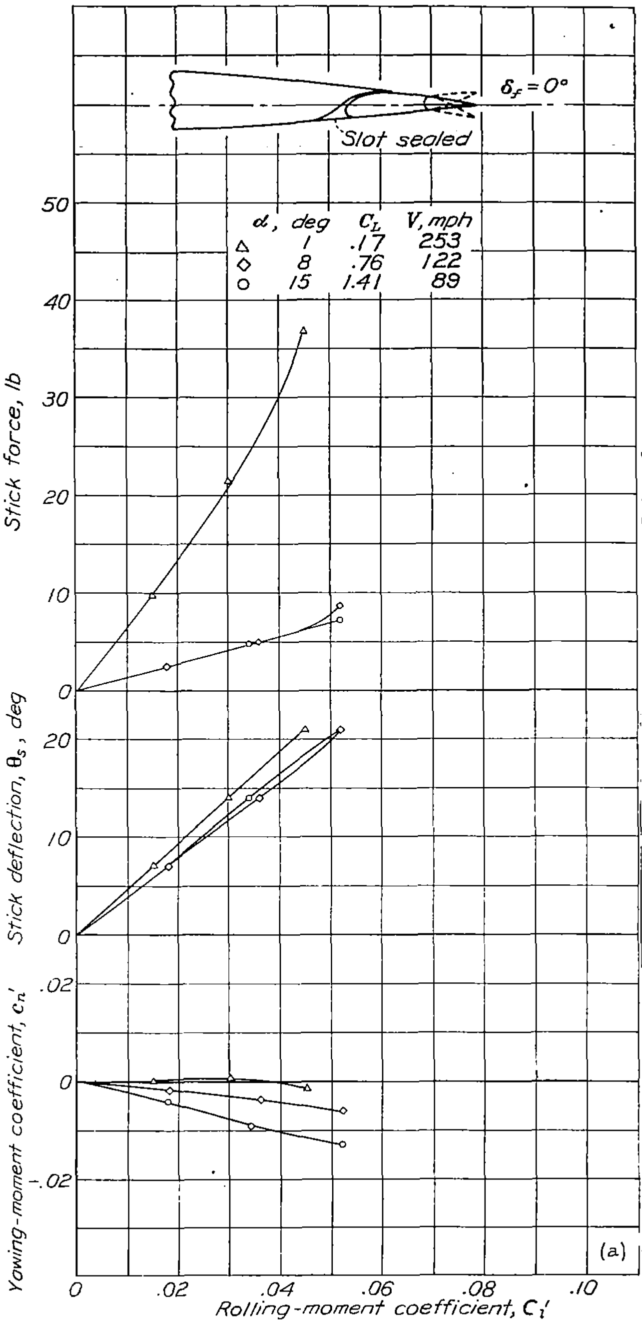


Figure 10a.- Slotted flap retracted.

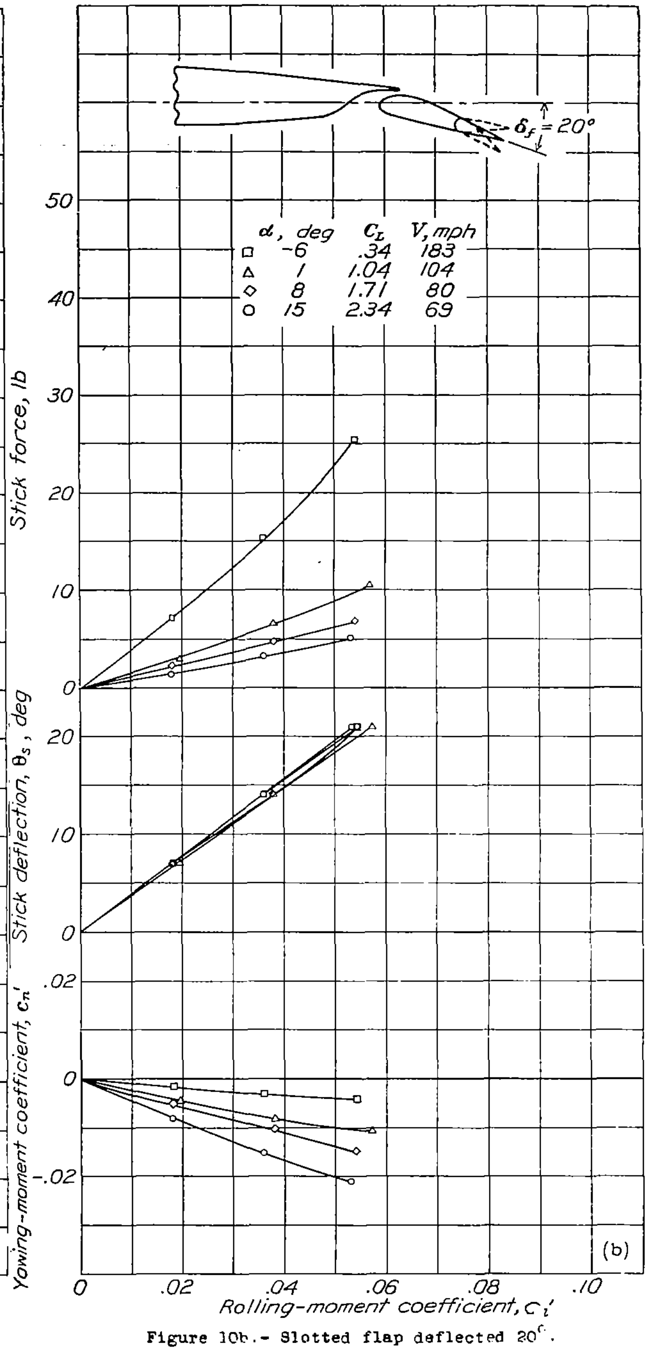


Figure 10b.- Slotted flap deflected 20°.

Figure 10a to b.- The characteristics of plain ailerons linked for equal deflections, maximum $\delta_p = \pm 15°$.

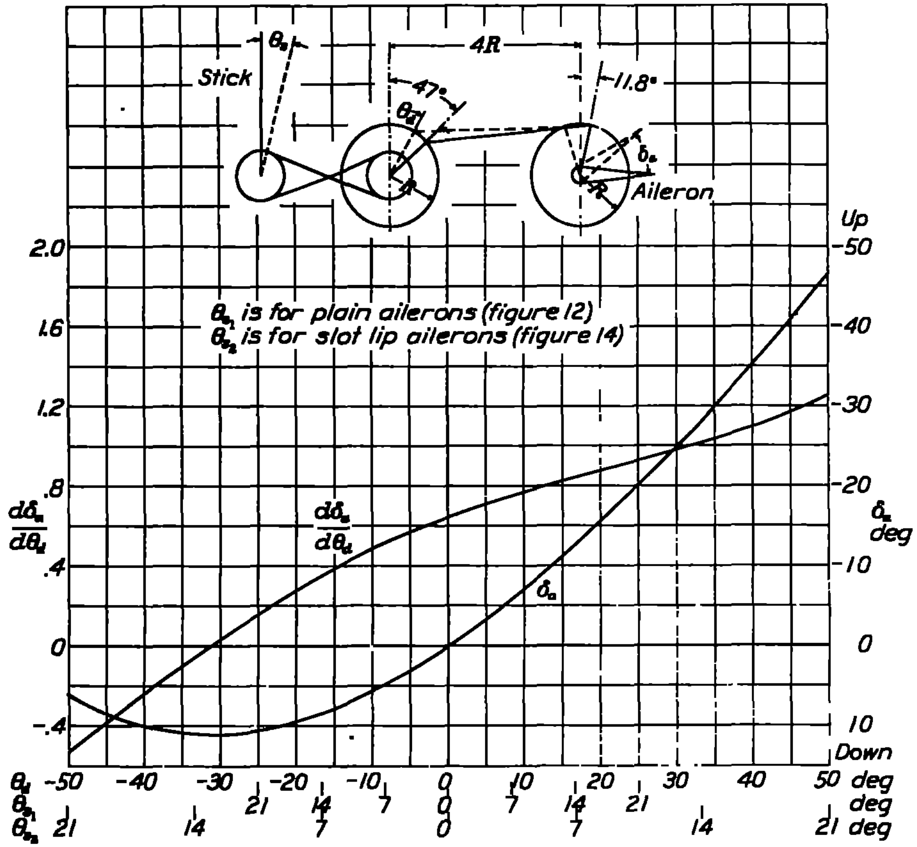


Figure 11.- Differential linkages.

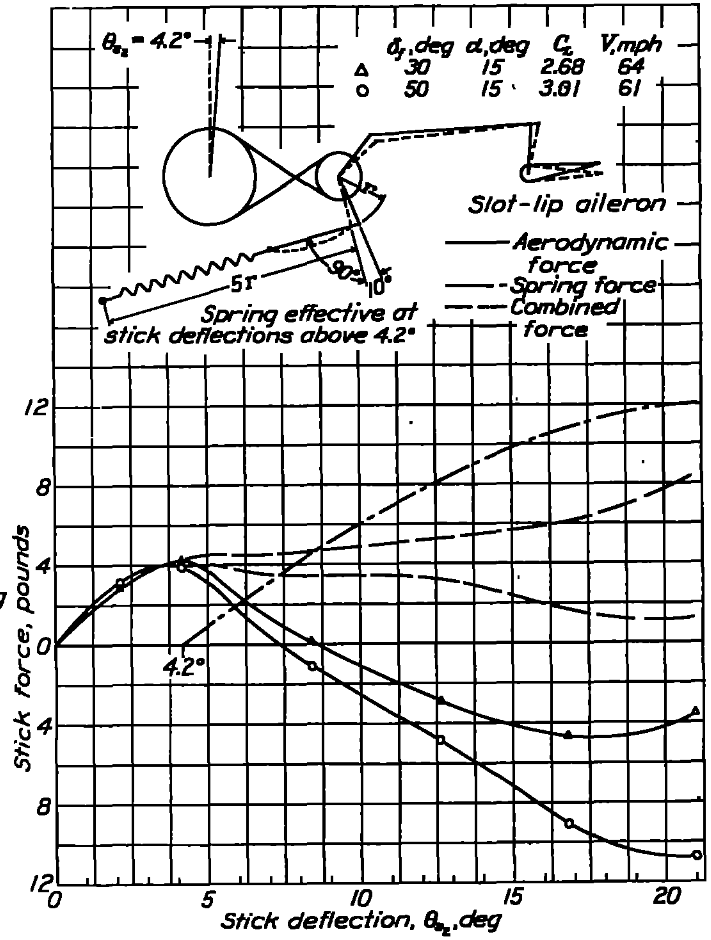


Figure 13.- The effect of springs on stick-force characteristics.

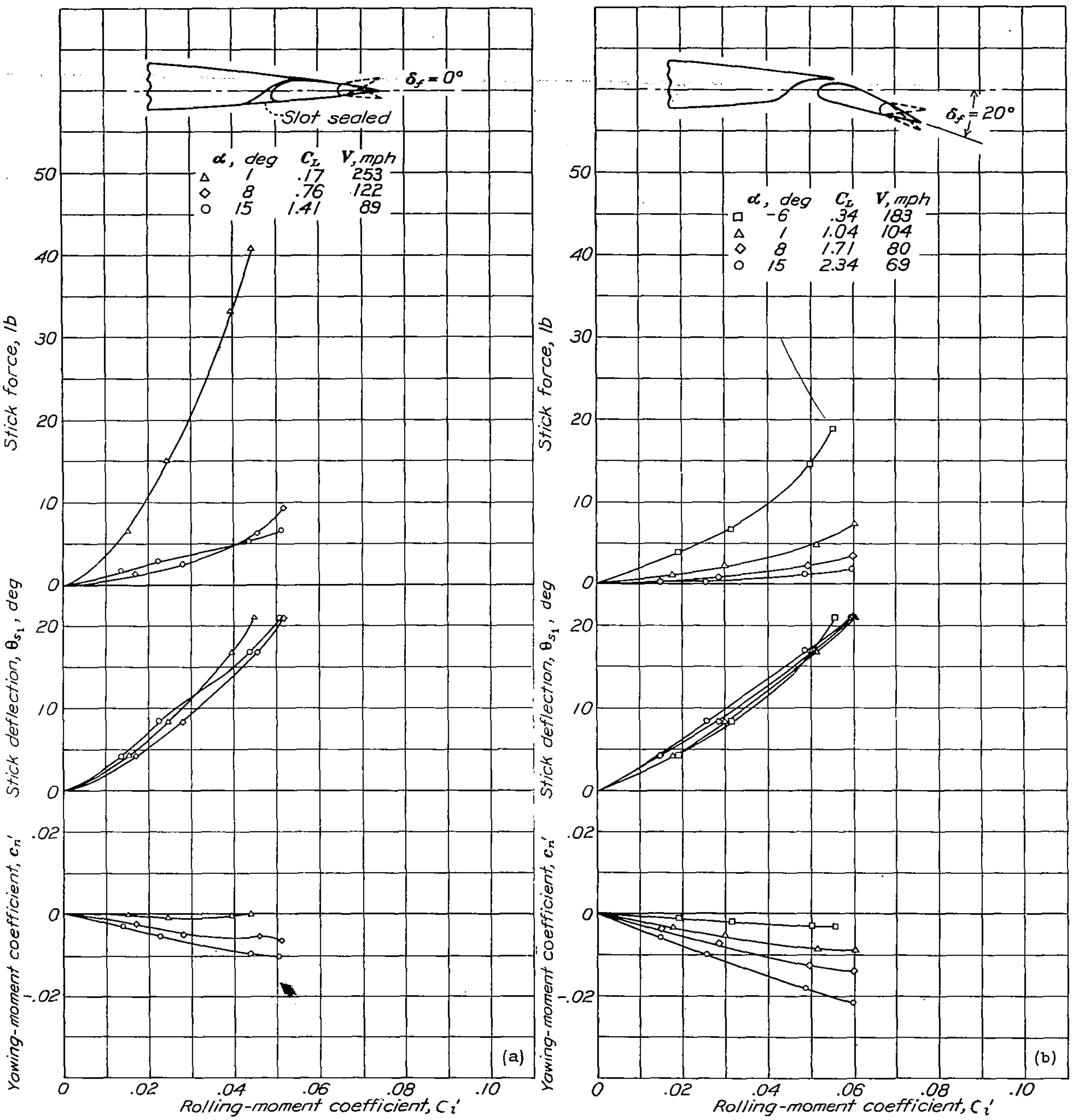


Figure 12a.- Slotted flap retracted.

Figure 12b.- Slotted flaps deflected 30°.

Figure 12a to b.- The characteristics of plain ailerons linked for differential operation to 10.7° and -19.7°.

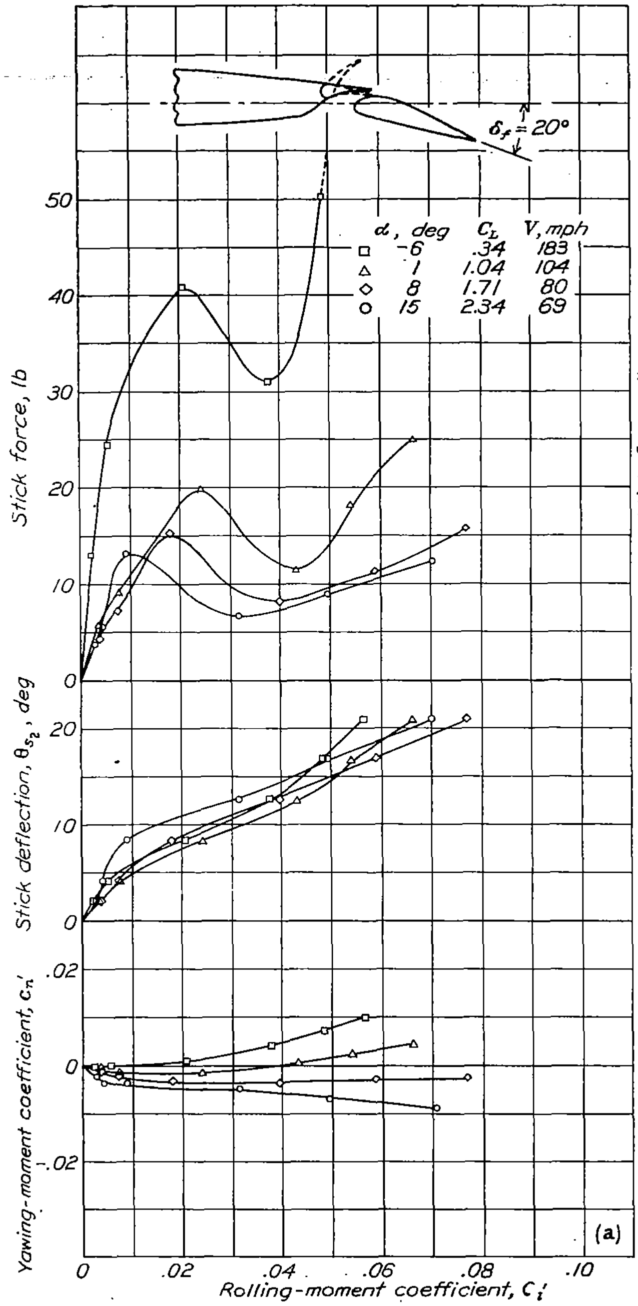


Figure 14a.- Slotted flap deflected 20°.

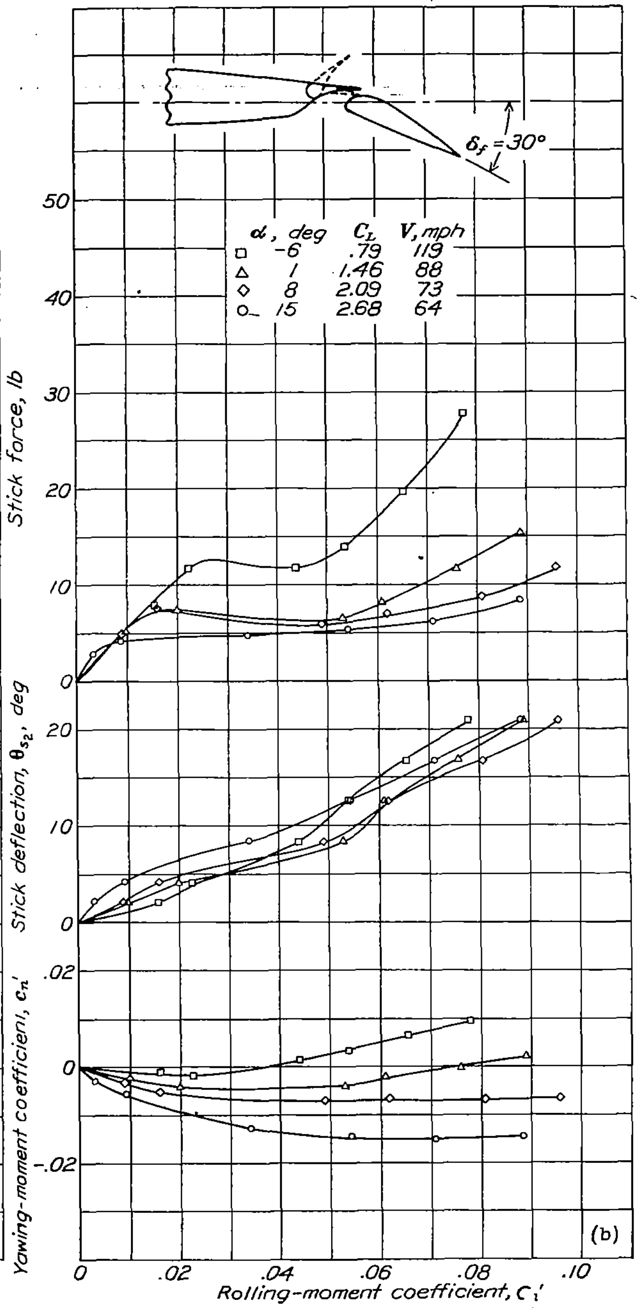


Figure 14b.- Slotted flap deflected 30°.

Figure 14a to d.- The characteristics of a slot-lip aileron system employing springs.

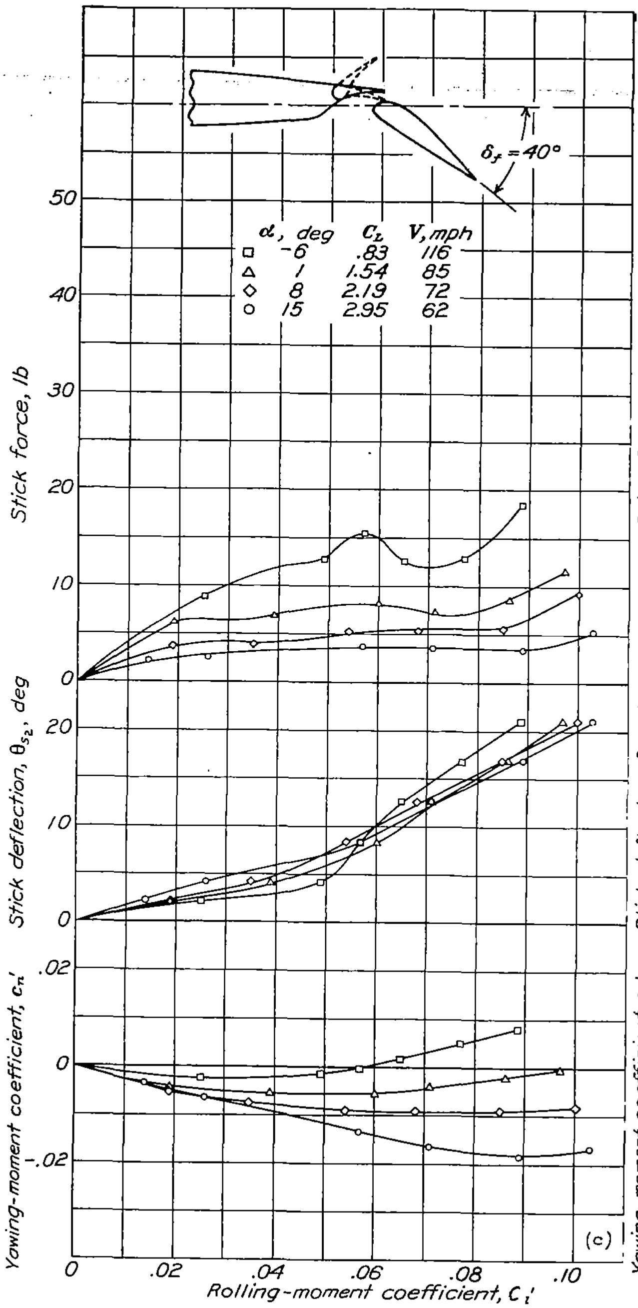


Figure 14c.- Slotted flap deflected 40°.

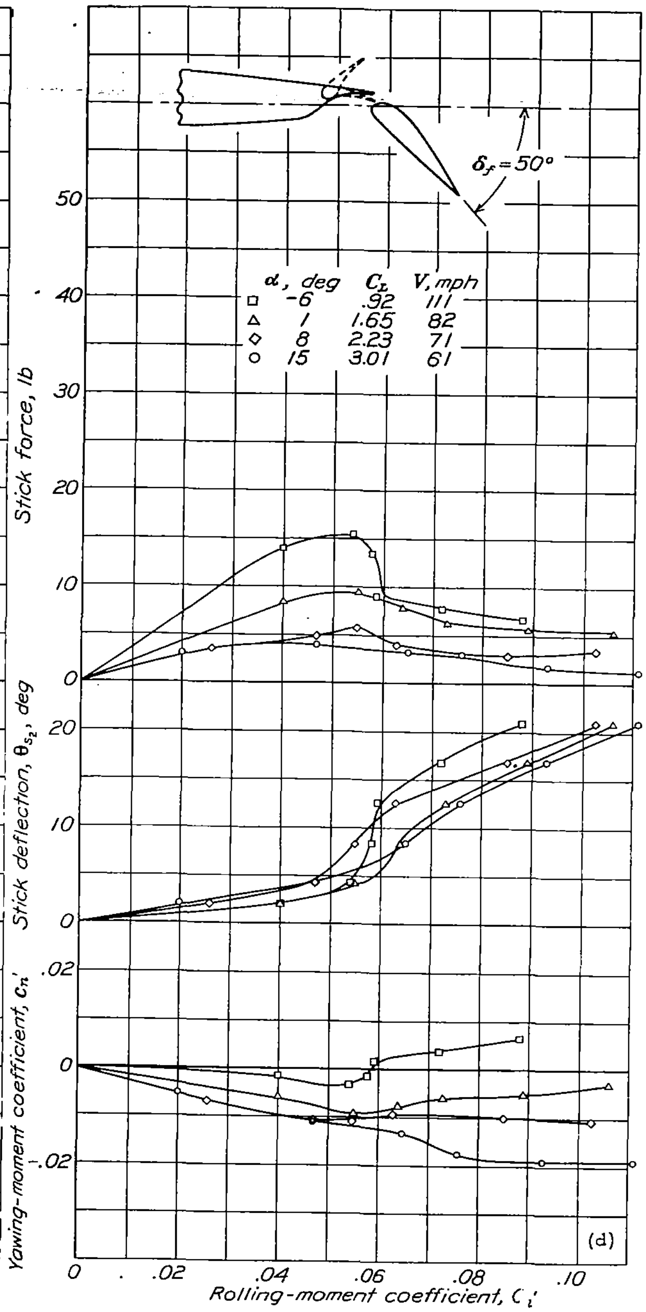


Figure 14d.- Slotted flap deflected 50°.

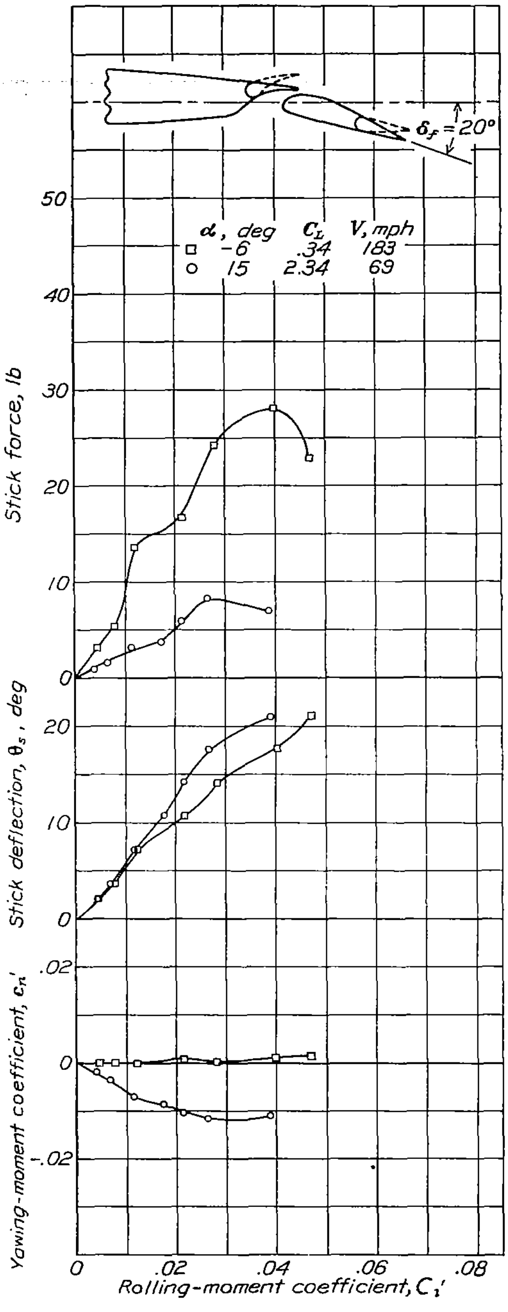


Figure 16.- The characteristics of a combination system with linkage A_2. Slotted flap deflected 20°.

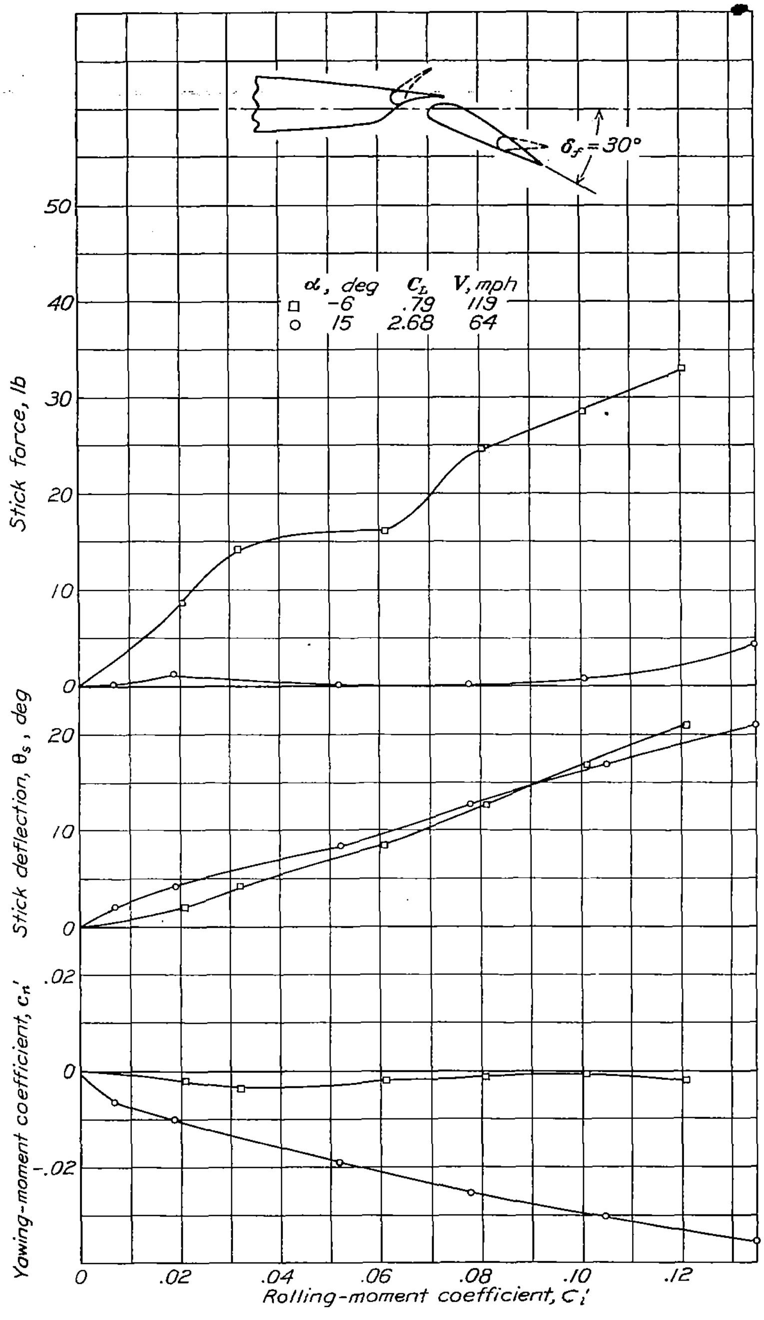


Figure 17.- The characteristics of a combination system with linkage A_3. Slotted flap deflected 30°.

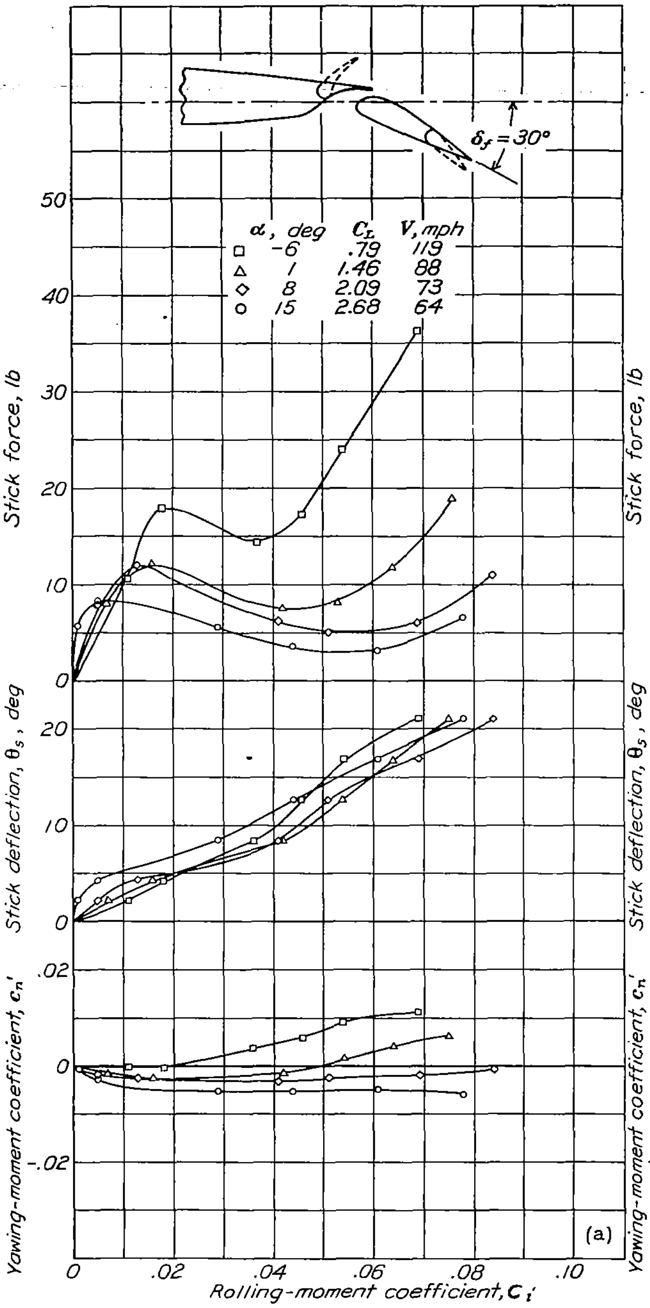


Figure 19a.- Slotted flap deflected 30°.

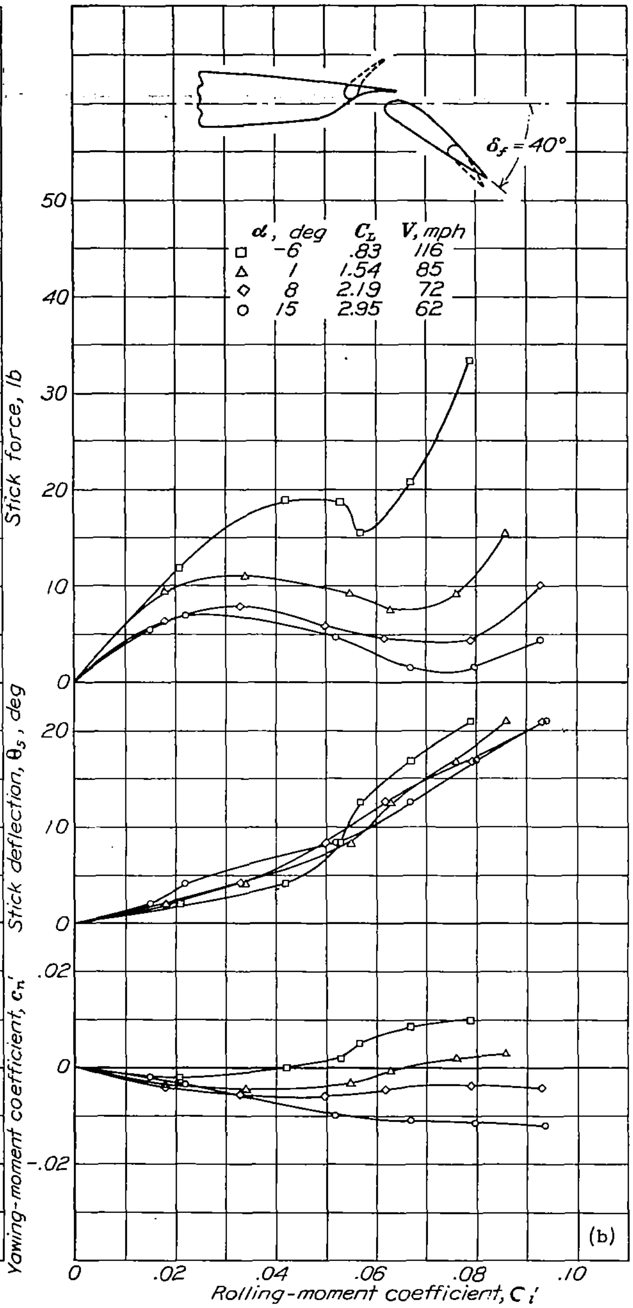


Figure 19b.- Slotted flap deflected 40°.

Figure 19a to c.- The characteristics of a combination system with linkage B_2.

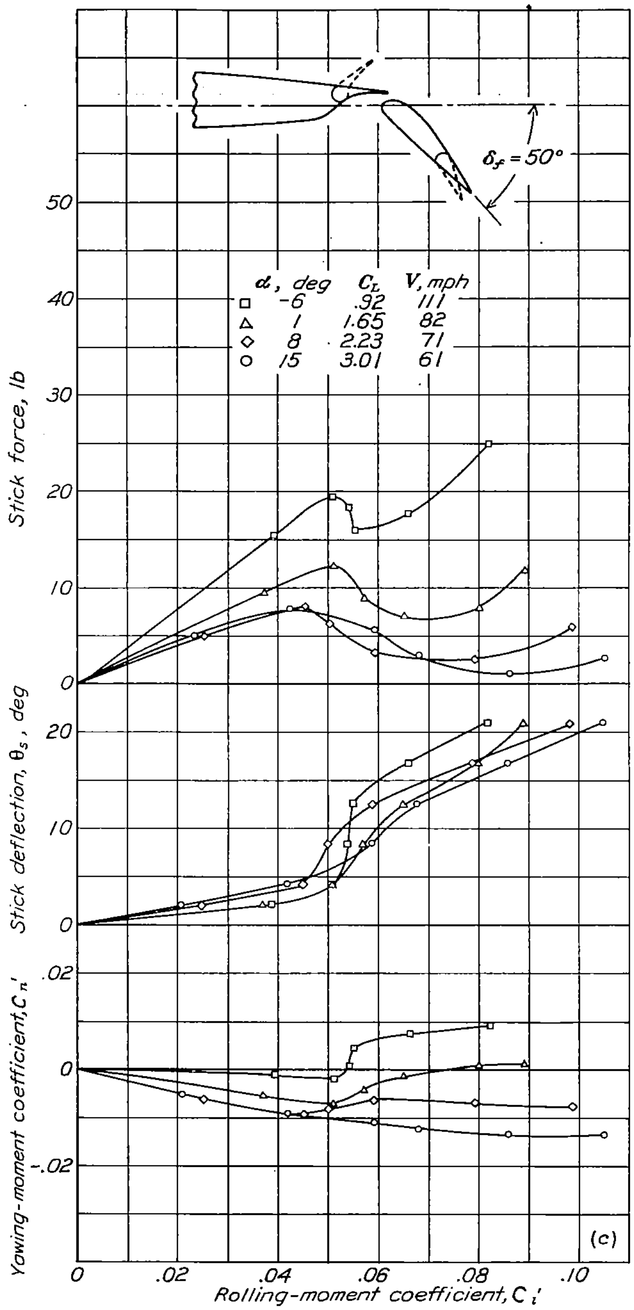


Figure 19c.- Slotted flap deflected 50°. The characteristics of a combination system with linkage B_2.